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Sex Differences in Visual Attention to the Mouth in Infancy: Implications for Language Acquisition

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An abstract of a thesis submitted to the Faculty of the
Laney Graduate School of Emory University
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Abstract

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Development of pre-linguistic communicative skills, like gesture, predicts acquisition of language in typically developing infants and toddlers. Prior to, and concurrent with, such communicative development, infants are attuned to social auditory and visual input, such that their visual behavior serves to index interest in, and predict later proficiency with, social-cognitive abilities. The current study proposes a role for visual attention preference for the mouths of speaking adults in the second year of life as facilitative of language development. Typically developing infants (26 male, 24 female) viewed scenes of child-directed speech, and eye-tracking data was collected longitudinally at 10 time-points from 2 to 24 months of age. Assessments of communicative and language development were also conducted throughout the first two years. Results indicate a peak in mouth fixation early in the second year of life, immediately preceding a period of known vocabulary growth. Sex differences in the chronology of this peak support a relationship between mouth fixation and language development. Sex differences in language measures indicate that females are precocious in vocabulary, gesture and language-related cognitive skill acquisition. Sex-specific developmental trajectories of the relationship between mouth fixation and language abilities suggest mouth fixation as potentially facilitative in the acquisition of language.

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As infants develop as social beings, able to interact with, request from, and generally communicate with their worlds, the acquisition of language is paramount. It has been well established that differences in language production in early childhood and school-age years, as relates to various socio-economic, educational and cognitive functioning factors, have implications for understanding child outcomes (McLoyd, 1998; Rowe & Goldin-meadow, 2009; Rowe, Ozçalişkan, & Goldin-Meadow, 2008). While measuring and assessing language in an emerged state and evaluating developmental increases throughout early childhood speaks to factors that may impact the continued progress and outcome of language acquisition, this type of study does not address the pre-linguistic developmental trajectory. Social-communicative processes emerging in infancy hold potential significance for later language acquisition and development. This has been addressed through demonstration that pre-linguistic communicative skill development, particularly gesture, is predictive of later vocabulary acquisition and language development. These communicative behaviors precede and seem to predict word use and language acquisition, however, even their emergence toward the end of the first year of life leaves unexplored the possibility of enormous development of myriad processes important for language acquisition prior to the emergence of these skills. Further, as these nonverbal communicative skills emerge, other less behaviorally recognizable means of interacting with the social environment may play important roles in the progression of language and communicative development. Namely, preferential visual attention of pre-verbal infants may facilitate the development of language through directing attentional resources toward language-relevant stimuli.

Gesture Use Predicts Language Acquisition

Prior to the emergence of language in infants, the development of other communicative skills and behaviors, like gesture, is predictive of language development. The types of gestures produced and their co-occurring behaviors during very early stages of language acquisition are strongly related to a child's subsequent development of more complex language (Brooks & Meltzoff, 2008; Iverson & Goldin-Meadow, 2005).

Pre-linguistic use of gesture plays a predictive and potentially facilitative role in the emergence of language skills. Use of gesture for a given referent tends to precede use of words for the same referent, as demonstrated in infants followed from 10 to 24 months-of-age (Iverson & Goldin-Meadow, 2005). More items were referred to by these infants solely by gestures, such as point and show gestures, at early months, and solely by words later in development. Gesture use in conjunction with emerging language skill appeared to facilitate language development, whereby early use of *supplementary* gesture-word combinations—in which gesture and word did not necessarily refer to the same thing—predicted earlier transition to two-word speech (Iverson & Goldin-Meadow, 2005). The supplementary nature of these gesture-word combinations suggests that the use of gesture in combination with speech plays a facilitative role in speech production, regardless of gesture-word congruence.

While co-occurrence of gesture and word production may facilitate the use of spoken language, gesture also predicts early comprehension of language. Early communicative gestures, exhibited at 8 months of age in a longitudinal study, accounted for significant variance in vocabulary comprehension at 12 months, as well as vocabulary production at 24 months (Bavin et al., 2008). An even better predictor of vocabulary production at 24 months was gesture at 12 months, occurring as more concrete language skill was becoming evident (Bavin et al, 2008). This finding is corroborates the importance of gesture used in conjunction with emerging language skill evident in the facilitative nature of supplementary gesture-word combinations and their impact on language outcome (Iverson & Goldin-Meadow, 2005).

Expanding the association between early gestures and language development to more long-term influence, Rowe, Özçalişkan and Goldin-Meadow (2008) tested the association between infants' gesture production at 14 months and their receptive vocabularies at 42 months of age. Multiple quantifiers of gesture at 14 months were positively associated with receptive vocabulary at 42 months, indicating long-term association between early gesture and language development, beyond the initial transition from gesture to speech (Rowe et al., 2008).

While early gesture development appears to predict both language comprehension and production, both in the early stages of speech production and in later measures of comprehension, gestures used in infancy are also strongly associated with adaptive communicative ability—the functional use of language and communicative skill. To elucidate this relationship most clearly, research has focused on those with deficits in social and communicative adaptive ability, with concurrent language concerns, whereby variability in level of functioning can be assessed. In children with Autism Spectrum Disorder (ASD), a core and common feature of which tends to be language delay and deficits in social abilities, gesture use assessed in preschool years is predictive of adaptive functioning outcome at school-age (Luyster, Qiu, Lopez, & Lord, 2007). Further, while gesture in early childhood is predictive of adaptive functioning, verbal skills at preschool age serve to predict later social-adaptive functioning in children with high-functioning ASD (Venter, Lord, & Schopler, 1992). The coalescence of these areas of communicative skill appear to allow children the best means for developing social and communicative adaptive skill, and best predict adaptive functioning later in childhood. Thus, the chronology of communicative and language development has profound impact on later adaptive functioning.

Early Comprehension of Language Predicts Production

Production of nonverbal communicative behavior predicts and likely facilitates the production of spoken language. Prior to—and during early stages of—the production of speech, however, receptive vocabulary and language comprehension may be demonstrative of the earliest connections between communicative behavior and language learning. Moreover, receptive vocabulary can inform on the relationship between initial comprehension, and the eventual transition to production of language. Cognitive and linguistic ability in later childhood can be predicted by both receptive and expressive vocabulary at the end of the second year of life (Fernald & Marchman, 2012). As receptive vocabulary begins to amass prior to a child's first spoken language, it holds enormous potential as a contributor to our understanding of the development of language skills pre-linguistically. In fact, measures of language comprehension in the first year of life serve as far better predictors of language production later in early childhood than do first emerging language production skills at the same age of measurement (Fenson et al., 1994). This predictive relationship further supports the proposition that the earliest indicators of linguistic and communicative development are most relevant in understanding language production outcomes and the developmental trajectory of language acquisition and development.

Role of Preferential Attention in Language Acquisition

Strong, predictive associations between early developmental processes related to communicative ability and early childhood language outcome have been well established, however, the mechanism whereby these early emerging communicative skills relate to, or facilitate, language acquisition remains unclear. One compelling hypothesis is that the early emergence of these explicitly communicative skills increases the opportunities afforded the infant for social interaction, and the extent of an infant's language exposure (Iverson & Goldin-Meadow, 2005; Goodwyn, Acredolo, & Brown, 2000). It would follow that early communicative skill directs the infant's behavioral and environmental interactions toward those which are more verbal or social, attuning perceptual systems to social input.

Also delineating increased opportunity for social interaction and language exposure in infants is preferential attention toward social or verbal elements in the environment. Innate preferential attention for human and social stimuli has been demonstrated for both auditory and visual perception (Farroni, Menon, & Johnson, 2006; Johnson & Newport, 1991), increasing a child's exposure to social content, and likely facilitating social development. In fact, decreased visual attention to eyes and faces during the viewing of social scenes has been associated with increased social disability in children with ASD (Klin, Jones, Schultz, Volkmar, & Cohen, 2002). Receiving visual and interactive input in conjunction with auditory exposure to speech sounds enriches typically developing infants' learning of phonetic language, facilitating this process (Kuhl, Tsao, & Liu, 2003). Further, preferential auditory attention toward speech sounds (Vouloumanos & Werker, 2007), and apparently concurrent increased visual fixation on the mouth of others (Jones & Klin, 2013; Lewkowicz & Hansen-Tift, 2012) suggest a potential mechanistic link between such attentional attunement and the development of language.

Increases in visual preference for the mouths of others have been documented at various points in the first two years of life in typically developing infants. Lewkowicz and Hansen-Tift (2012) demonstrate such a peak in preferential viewing of the mouths of speaking adults between 8 and 9 months of age, following a decrease in preferential viewing of the eyes of others. The authors suggest a link between such shifts and language development, and posit that this shift is chronologically linked with learning to speak. They suggest that visual attention on speaking mouths allows infants access to additional audio-visual information that facilitates such learning.

We have noted a similar phenomenon in data previously analyzed for another publication, whereby infants increase visual attention to the mouth, seeming to peak between 16 and 18 months of age (Jones & Klin, 2013). This peak in visual attention to the mouth immediately precedes a well-established surge in language learning and vocabulary production (Nazzi & Bertoncini, 2003). While both sets of data find a shift in preferential viewing over time, and situate this shift in relation to early stages of speech development, the two sets of findings are discrepant in their chronology: one shows an earlier shift towards fixation on the mouths of talking faces, whereas the other shows that shift happening later in development.

One potential account for this difference is the cross-sectional nature of Lewkowicz and Hansen-Tift's study, collecting data on individual infants at various ages across the first year of life, whereas Jones and Klin followed infants longitudinally over the first two years of life. The differing chronology in these two studies may be further reconciled by an interesting factor not yet explicitly investigated: namely, the sex of participants. Jones and Klin's data were collected in males only, whereas approximately half of the Lewkowicz & Hansen-Tift sample was female. Consistent with the notion that the observed change in preferential attention patterns is associated with speech development, but also consistent with the notion that infant and toddler girls are known to be precocious speech and language learners relative to boys (Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Schachter, Shore, Hodapp, Chalfin, & Bundy, 1978), the disagreement in chronology in these data would suggest that the increase in mouth fixation should occur at an *earlier* developmental time in girls relative to boys.

Sex Differences in Communicative Development

Such sex differences are evident in other, more overt behavioral correlates of language development and communicative skill. Females typically begin speaking in multi-word phrases approximately three months earlier than males, pairing two words as early as 22 months of age. This is preceded by a similar sex difference in the chronology of emerging gesture-word pairings in infants learning to speak, girls producing meaningful gesture-speech combinations at approximately 19 months of age (Özçalişkan & Goldin-Meadow, 2010). Even before the emergence of language, differences in arm preference in reaching gestures between sexes at 7 months of age may serve to index differences in neural development precursory to the emergence of language (Humphrey & Humphrey, 1987). Preference of hand or arm use in infants during communicative behavior has been suggested as a proxy for hemispheric lateralization occurring in the brain that may be requisite for speech development. While some recent research points to this difference in the acquisition of communicative skills, and it is historically noted that a sex difference in early aspects of language development is robust, the existing literature is largely anecdotal, suggesting that females talk earlier than males. Given the historical assumption that sex differences exist in early language development, and more contemporary research suggesting sex differences in development of other communicative behaviors in infancy, we hypothesize that males and females in the current sample will differ in their language acquisition, and related skill development, throughout the first two years of life.

Sex differences do seem to suggest precocious communicative development in girls, as demonstrated both directly (in language and vocabulary production and development) as well as more peripherally (in gesture and in other communicative predictors—and potential facilitators—of language development). Thus, it would follow that if we are correct in the hypothesis that preferential visual attention to the mouth marks or facilitates the emergence of language, directing the infant’s exposure to language input, a coinciding sex difference evident in the chronology of shifting visual attention to the mouth should be present. While data from both Lewkowicz and Hansen-Tift (2012) and Jones and Klin (2013) suggest a potential link between mouth fixation and the process of language learning, hypothesizing a mechanism of increased exposure to (and infant interest in) visual input related to speech, neither fully addresses this hypothesis with any measure of language outcomes or early behavioral indicators of language and communicative development.

The present study seeks to affirm mouth fixation’s predictive utility and potentially facilitative role in language development and to demonstrate that visual fixation on the mouth serves as an index for other developmental increases in measures of gesture, communicative ability and language comprehension and production. Further, in keeping with established female precociousness in the emergence of language, we hypothesize that a sex difference in the chronology of infant visual attention to the mouth, and its relation to language, will be evident. Further, visual attention to the eyes has been suggested as central to social development in infancy, and preferential attention to the eyes has been well documented throughout most of infant and toddler development. As such, we hypothesize that increased mouth-looking will decline following its peak immediately preceding language acquisition. Thus, we anticipate that the trajectory of attention to the mouth over the first two years of life will be non-linear.

Methods

Participants

Data collection occurred in the Autism Program of the Yale Child Study Center, New Haven, CT, and at the Marcus Autism Center, Children’s Healthcare of Atlanta and Emory

University School of Medicine, Atlanta, GA. Human Investigations Committees at the Yale University School of Medicine and at the Emory University School of Medicine approved the research protocol as non-significant risk, and the data collected were used for research purposes only, with no relationship to clinical care. Families were free to withdraw from the study at any time. Infants were recruited in New Haven via collaborations with Yale–New Haven Hospital OB-GYN and Pediatrics departments, as well as by advertisements on pertinent websites and via direct mailing, and in Atlanta at the Marcus Autism Center, and via contact with Atlanta pediatric practices.

Participants in this study were recruited as part of the typically developing control group within a large-scale longitudinal study of infants at high risk for developing an Autism Spectrum Disorder (ASD). Thus, exclusionary criteria for this typically developing sample included any familial history (first-, second-, or third-degree relatives) of ASD or developmental delay, as well as any pre- or perinatal complications. Infants were all full-term and no visual or auditory concerns were reported throughout development.

Direct Clinical Assessment

All participants were followed longitudinally, and were evaluated at 6, 9, 12, 15, 18 and 24 months of age, with various clinical developmental assessments of cognitive, communicative and adaptive abilities.

The *Mullen Scales of Early Learning* (Mullen; Mullen, 1995) were administered at 6, 12, 18, and 24 months of age to obtain standardized measures of general cognitive functioning. The Mullen is an integrated measure assessing an infant’s cognitive and motor abilities across five scales—Gross Motor, Visual Reception, Fine Motor, Expressive Language, and Receptive

Language—yielding a T-score (M = 50, SD = 10) and a normed age equivalent for each scale, along with a full-scale Early Learning Composite score.

The *MacArthur-Bates Communicative Development Inventory* (CDI; Fenson et al., 2006) was administered at either 6 or 9 months of age, and then at 12 and 18 months of age to obtain data about verbal and gestural communicative development. The CDI is a parent report measure assessing comprehension and production of vocabulary and gesture, and a child's achievement of various communicative milestones, such as imitation. It yields global scores on comprehension and production of vocabulary and of gesture, four of which will be of particular importance to the present study: Understands, Understands and Says, Early Gestures and Total Gestures. Scores quantify the words understood and produced, from a list of developmentally appropriate vocabulary, and quantify deictic and conventional gestures understood and produced, from a list of developmentally appropriate early- and late-emerging gestures.

Eye-tracking Data Acquisition

Eye-tracking data was collected every month from 2 to 6 months of age, and then at 9, 15, 18 and 24 month visits. Visual scanning was measured with eye-tracking equipment (ISCAN). Analysis of eye movements and coding of fixation data were performed with software written in MATLAB. Two settings for eye-tracking data collection were used in this study. One eye-tracking laboratory was optimized for infants between the ages of 2 and 6 months, and a second setting was optimized for infants and toddlers from 9 to 24 months. The primary distinction between the two settings was the use of a reclined bassinet for younger infants versus the use of a car seat for older infants and toddlers. The eye-tracking data-collection hardware and software were identical in both settings, and all aspects of automated stimuli presentation, data collection and analysis were also identical. To obtain optimal eye imaging with infants in the reclined bassinet, eye-tracking cameras and an infrared light source were concealed within a teleprompter. In the toddler laboratory, eye-tracking cameras were mounted beneath a computer display monitor. The display monitor was mounted flush within a wall panel. In both laboratories, eye tracking was accomplished by a video-based, dark pupil/corneal reflection technique with hardware and software created by ISCAN, with data collected at 60 Hz. In both laboratories, audio was played through a set of concealed speakers. Infants were placed in a modified travel bassinet, mounted on a table that was raised and lowered at the beginning of each session to standardize the positioning of the infant's eyes relative to the display monitor. In the toddler laboratory, children were seated in a car seat in front of the computer screen on which the videos were presented. As in the infant laboratory, the car seat was raised and lowered so as to standardize the position of each child's eyes relative to the display monitor.

Stimuli. Children were shown video scenes of a female actor looking directly into the camera and playing the part of a caregiver: entreating the viewing toddler by engaging in childhood games (for example, playing pat-a-cake) (Figure 1a). The actors were filmed in naturalistic settings that emulated the real-world environment of a child's room, with pictures, shelves of toys, and stuffed animals. We used naturalistic stimuli (for example, dynamic rather than static stimuli, and realistic rather than abstracted or reductive scenes). At each data-collection session, videos were drawn in pseudo-random order from a pool of 35 in total. Both the 'caregiver' video stimuli analyzed here (35 videos), as well as videos of infant and toddler interaction ('peer-play' videos, as described in Shultz, Klin, & Jones (2011), for another set of experiments not yet analyzed) were presented. Video stimuli were presented in pseudo-random order.

There were no between-group differences in duration of data collected per child between sexes ($t_{331} = 1.182$, $p = 0.767$). Failed data collection sessions occurred as the result of an infant falling asleep, crying, or becoming too fussy to watch the videos. Reasons for failure were recorded in data collection reports for each session and maintained in a database; no systematic difference in reasons for failure could be discerned between the two sexes. At each data collection session, approximately 30% of the videos shown to a child were novel, whereas the remaining 70% were repeated from previous sessions (from both the immediately preceding session as well as from any prior session beginning at month 2 onwards). This balanced the need for repeated measures to the same stimulus video with the need for novelty.

Caregiver videos were presented as full-screen audiovisual stimuli on a 20-inch computer monitor (refresh rate of 60 Hz noninterlaced); in 32-bit colour; at 640 × 480 pixels in resolution; at 30 frames per s; with mono-channel audio sampled at 44.1 kHz. Stimuli were sound and luminosity equalized, and were piloted before the start of study in order to optimize engagement for typical infant and toddler viewers. Regions of interest (eye, mouth, body and object) were bitmapped in all frames of video (Figure 1a).

Experimental protocol. Infants and toddlers were accompanied at all times by a parent or primary caregiver. To begin the experimental session, the participant (infant or toddler) and caregiver entered the laboratory room while a popular children's entertainment video played on the display monitor. The child was buckled into the bassinet or car seat. Eye position relative to display monitor was then standardized for each child by adjusting the seat or bassinet location. Viewers' eyes were 28 inches (71.12 cm) from the display monitor, which subtended an approximately 24° × 32° portion of each viewer's visual field. Lights in the room were dimmed so that only content presented on the display monitor could be easily seen. During testing, both experimenter and parent were out of view from the child but were able to monitor the child at all times by means of an eye-tracking camera and by a second video camera that filmed a full-body image of the child.

Visual-fixation patterns were measured with eye-tracking hardware (ISCAN). To begin the process of data collection, after the child was comfortably watching the children's video, calibration targets were presented onscreen by the experimenter. This was done using software that paused the playing video and presented a calibration target on an otherwise blank background. A five-point calibration scheme was used, presenting spinning and/or flashing points of light as well as cartoon animations, ranging in size from 1° to 1.5° of visual angle, all with accompanying sounds. For the infants, calibration stimuli began as large targets, ≥10° in horizontal and vertical dimensions, which then shrank through animation to their final size of 1° to 1.5° of visual angle. The calibration routine was followed by verification of calibration in which more animations were presented at five on-screen locations. Throughout the remainder of the testing session, animated targets (as used in the calibration process) were shown between experimental videos to measure drift in calibration accuracy. In this way, accuracy of the eye-tracking data was verified before beginning experimental trials and was then repeatedly checked between video segments as the testing continued. In the case that drift exceeded 3°, data collection was stopped and recalibration was carried out before further videos were presented.

Analysis of eye movements. Analysis of eye movements and coding of fixation data were performed with software written in MATLAB (MathWorks). The first phase of analysis was an automated identification of non-fixation data, comprising blinks, saccades and fixations directed away from the presentation screen. Saccades were identified by eye velocity using a threshold of 30° per s (Leigh & Zee, 1999). We tested the velocity threshold with the 60-Hz eye-tracking system described above and, separately, with an eye-tracking system collecting data at 500 Hz (SensoMotoric Instruments GmbH). In both cases saccades were identified with equivalent reliability as compared with both hand coding of the raw eye-position data and with high-speed video of the child's eyes. Blinks were identified as described in Shultz et al (2011). Off-screen fixations (when a participant looked away from the video) were identified by fixation coordinates beyond the stimuli presentation screen.

Eye movements identified as fixations were coded into four regions of interest that were defined within each frame of all video stimuli: eyes, mouth, body (neck, shoulders and contours around eyes and mouth, such as hair) and objects (surrounding inanimate stimuli) (Figure 1b). The regions of interest were hand traced for all frames of the video and were then stored as binary bitmaps (through software written in MATLAB). Automated coding of fixation time to each region of interest then consisted of a numerical comparison of each child's coordinate fixation data with the bitmapped regions of interest.

Data analytic plan

To identify a peak in mouth fixation, both non-parametric correlation and locally weighted polynomial regression were employed. Repeated measures ANOVA was used to identify sex differences in developmental trends of both mouth fixation and language measures across age. To assess relationships among age, mouth fixation and language measures, non-parametric Spearman's correlation was used. As is expected in research with human infants, there were some missing data points across measures. All but two participants (1 male and 1 female) were missing eye-tracking data for at least one session (though most were missing one or two sessions from the earliest months of data collection, and only 8 males and 6 females were missing more than 4 of the total 10 sessions). 7 males and 6 females were missing CDI data for one of the three time points. 6 males and 4 females were missing Mullen data at various time points. In running all correlation and regression analyses, only existing data were used. In repeated measures ANOVA, analyses were run using both list-wise deletion for participants with missing values, as well as mean imputation (replacing missing data with age- and sex-specific group means) and these results were compared.

Results

Peak in Mouth Fixation

Consistent with our predictions, visual fixation on the mouth appears to increase, with a peak in the second year of life. Mouth fixation across age can be seen in Table 1 and Figure 1b. In assessing the presence of such a peak, two approaches were used to demonstrate the existence of a peak in mouth fixation during the second year of life. First, given our *a priori* assumption that developmental trends in infancy would not be linear, we used a non-parametric measure of correlation to detect the age of mouth fixation peak.

To do this, Spearman's rho was calculated at progressively increasing age brackets along the first two years of life, to find the age at which a relationship of monotonic increase shifted to one of monotonic decrease. This yielded a peak in mouth fixation of 14.8 months, across the full sample of infants and eye tracking sessions. At such a peak, a significant positive association between age and mouth fixation exists for ages less than or equal to the peak-age (age ≤ 14.8: $r_s = 0.344$, $p < 0.001$), and a co-occurring significant negative relationship between age and mouth fixation exists for all eye tracking data at ages greater than the peak-age, up to the oldest age of assessment (age > 14.8: $r_s = -0.210$, $p = 0.037$).

We took a second approach to locate the peak, using locally weighted polynomial regression (LOESS; Cohen, 1999). LOESS allows for fitting a polynomial surface or curve, determined by local predictors across small neighborhoods of data. The smoothness of the curve is determined by a smoothing parameter, or bandwidth, selected such that the radius of each neighborhood of data contains that specified percentage of the data points. LOESS was chosen as it does not assume linearity, nor does it require an a priori model, and rather serves as an exploratory visual smoothing tool. The resulting curve is shown in Figure 2. Using a smoothing bandwidth of 0.62 (indicating 62% of the data points comprising each local fit of a function), mouth fixation appears to peak at 18 months, at a peak value of 0.47.

Sex Differences

When the full sample was split into males and females, a difference was evident across both statistical frameworks, and was corroborated by repeated measures ANOVA (Table 1). Establishing the peak with non-parametric correlations, females exhibited a mouth fixation peak at 13.5 months (age $\leq$ 13.5: $r_s = 0.435$, $p < 0.001$; age > 13.5: $r_s = -0.276$, $p = 0.046$). Males appeared to increase mouth fixation with a significant positive association with age into the 15^{th} month of life, though did not display a significant negative association within the time period of our assessment (age $\leq$ 15: $r_s = 0.331$, $p < 0.001$; age > 15: $r_s = -0.002$, $p = 0.988$).

Upon examining males and females with a LOESS curve, male mouth fixation peaked at 19 months, slightly later than the female mouth fixation peak at 18 months of age. The value of the mouth fixation peak in females was 0.51, as opposed to 0.43 in males. In assessing the goodness of fit of the LOESS fitted models, corrected Akaike Information Criterion (AICc) were calculated for the LOESS model with males and females separate (AICc = -2.44), and for the model fit to the complete dataset (AICc = -2.29). In comparing AICc's, the model fit to the data with males and females separate is smaller (in this case, more negative), indicating a relatively better fit.

Sex differences are also evident in all measures of communicative and verbal ability and language development, as indicated by repeated measures ANOVA using mean imputation for missing values, displayed in Table 2. The same ANOVA employing list-wise deletion to account for missing values was limited by smaller sample sizes, as entire participants were removed from analysis if missing data for a single time point, thus sex differences did not reach significance for all scales and indices. Of those measures of language development that did not reach significance for sex differences, whereby females scored higher across early development, all exhibited trends in the same direction as analyses conducted with mean-imputed data. The Visual Reception scale of the Mullen, which does not specifically tap expressive or receptive language and communication abilities, did not differ by sex, nor did the Gross Motor ($F = 0.533$, $p = 0.662$) and Fine Motor ($F = 0.310$, $p = 0.818$) scales.

Mouth Fixation Predictive of Language Development

Once sex differences had been established both in mouth fixation and in language and communicative development measures, we wanted to assess whether there was a relationship between the peak in mouth fixation and the developmental trajectory of language acquisition. Using the sex-specific ages of apparent mouth fixation peak established with non-parametric correlations we examined the directionality of associations between mouth fixation and language development before and after this potentially facilitative peak in mouth fixation, as can be seen in scatterplots of the data (Figure 3). To approach this statistically, further Spearman’s rho’s were calculated to assess the relationship between mouth fixation and measures of language and communicative development prior to and at the age of mouth fixation peak, and in the months of data collection after the peak. Results of these correlations are found in Table 3 and Table 4. Notably, in females, measures were largely associated with age and not correlated with mouth fixation, prior to the peak, while significant negative associations existed after the peak between measures of vocabulary and mouth fixation, presumably during a period of decline in mouth fixation. A similar trend existed for the relationship between mouth fixation and total gesture in females, after the peak ($r_s = -0.507$, $p = 0.064$).

The CDI measures of a child's vocabulary comprehension and production ("Understands" and "Understands and Says") are each significantly correlated with the Mullen scale that taps expressive language and communicative ability (Expressive Language Scale) in the full sample of infants, as seen in Table 5. When this sample was divided by sex, only Females display a significant correlation, before age of mouth fixation peak, between Mullen Expressive Language, and "Understands," and "Understands and Says," respectively ($r_s = 0.963$, $p < 0.001$; $r_s = 0.849$, $p = 0.002$). Females continued to exhibit a significant relationship between "Understands and Says" and Mullen Expressive Language, after the age of mouth fixation peak ($r_s = 0.737$, $p = 0.006$). When analyzed by itself, the male group did not exhibit any significant inter-correlation between these measures of communicative and language ability, suggesting that the two measures may tap constructs that overlap more clearly in the early language development of females, while these two constructs may be disparate in males' development of language in infancy. An issue of power may be at play here, given the decrease in n when the sample is split into sexes, and further in the pre- and post-peak age groups. When each sex was analyzed without separating by mouth fixation peak, however, removing the concern about sample size in males, a significant correlation between CDI indices "Understands," and "Understands and Says," respectively with Mullen Expressive Language remained in females ($r_s = 0.682$, $p < 0.001$; $r_s = 0.773$, $p < 0.001$), and did not exist in males ($r_s = -0.064$, $p = 0.788$; $r_s = 0.102$, $p = 0.670$). This should be noted in considering future directions of research, as it indicates a potentially vast difference between the elements of the language development process that are assessed by each measure, and between the developmental trajectory of language acquisition in males and females.

Discussion

It is clear that language learning is not a developmental process occurring in isolation. The acquisition of language in infancy seems to be inextricably linked with other acquired skills, developmental milestones and communicative abilities. The acquisition of these skills and abilities, such as communicative gesture and milestones of social and physical development, appear to predict and facilitate the development of spoken language. The potentially facilitative role of these non-verbal communicative skills for language learning may derive from the increased opportunity for communicative experience they afford an infant. In keeping with such a hypothesis, the increase in mouth fixation evident in the current data, and its apparent relationship to, and immediate preceding of, a period of steady and dramatic vocabulary growth and communicative development may serve to increase an infant's exposure to information important for the acquisition of language.

While the two methods for statistically addressing the existence of a peak in mouth fixation in infancy placed the peak at different time points in the developmental trajectory, both yielded a similar pattern. Regardless of statistical approach, a pattern was evident of increasing mouth fixation at the end of the first year and beginning of the second year of life, peaking in the first half of the second year, and declining later in development. Naturally, a limitation in the current sample, due to inherent difficulties in working with human infants, was missing data. This was particularly important in considering data analytic methods utilized. Some methods of analysis employed here required either list-wise deletion, diminishing the sample size, or mean imputation, which limits the strength of conclusions drawn. In future analysis of this, and additional data, consideration will be given to Hierarchical Linear Modeling, which does not remove missing value cases, nor does it require imputation for analysis of a full sample. Further, such analysis would allow for better identification of the role of mouth fixation as it relates to the trajectories of language development in typically developing males and females, while considering longitudinal dependencies.

In the present analyses, despite stated limitations, the same pattern of a peak in mouth fixation emerging early in the second year of life was evident, irrespective of which of the two analytic methods were employed. This pattern is consistent with the claim made by Lewkowicz and Hansen-Tift (2012) that infants increase their mouth-looking in infancy, though the current data situate the peak of this increase later in development.

The chronology of the observed peak in mouth fixation, occurring in the first half of the second year of life and shortly prior to a developmental period of dramatic word-learning and increased language production, lends itself to the interpretation that this mouth fixation increase is related to language learning. Our data do not demonstrate a predictive role of mouth fixation peak for language outcomes when looking at the full sample of infants. When the sample is separated by sex, however, mouth fixation appears to predict, and perhaps even facilitate, language learning and production.

A sex difference is evident in the mouth fixation trajectory, in both its developmental chronology and in the quantity of mouth-looking. Taken together with the temporal situation of the mouth fixation peak and the established differences in language learning timelines between males and females, the presence of a sex difference in mouth fixation supports the notion that mouth fixation may index language acquisition. Measures of language and communicative development and ability indicate a role for the peak in mouth fixation as a marker of or facilitative process for subsequent acquisition of vocabulary and communicative abilities.

Measures of language and communicative development, on their own, suggest marked sex differences in the development of language and communicative skills in the first two years of life. ANOVA indicates a difference in the trajectory of increase in the Expressive and Receptive Language scales of the Mullen, as well as the comprehension and production measures of language and communicative skill on the CDI, whereby females acquired more words and communicative skills by the final age assessed, and did so more quickly overall, than did their male peers. The lack of such a difference in the other scales of the Mullen, which do not tap the development of language or communication, but rather processing ability, memory and motor skills, indicates a sex difference specific to language development, rather than to global cognitive functioning. This finding is consistent with the historical literature of early language acquisition in females, and with current literature suggesting sex differences in more peripheral behavioral indicators of communicative skill. Such concrete evidence of dramatically different language and communicative skill acquisition in the first two years of life, however, between males and females is crucial for continued research in this area, and is unique to this study.

While as a full sample the current data do not suggest any change in the relationships between either age or mouth fixation, respectively, and the development of language skills, upon separating the data by sex, a striking pattern emerges. Separating the data into eye-tracking and assessment data collected prior to the mean age of mouth fixation peak in females (as established with non-parametric correlation: 13.5 months in females and 15 months in males), these associations look quite different. In females, age is significantly positively associated with all vocabulary and gesture indices of the CDI, and with the vast majority of scales within the

Mullen's cognitive assessment of language development, leading up to the age of mouth fixation peak.

Post peak, at which point mouth fixation exhibits a negative correlation with age during its period of slight decline, age no longer relates significantly to any of these measures, except for the Expressive Language scale on the Mullen. Conversely, while mouth fixation is neither associated with nor predictive of language and communicative ability prior to the peak, after the age of mouth fixation peak this is no longer the case. As age serves less of a role in predicting language development post-peak, mouth fixation exhibits a strong negative correlation with CDI measures of vocabulary comprehension and production, and a trending negative correlation with communicative gestures used and understood. Given mouth fixation's decline across age post-peak, this negative relationship between mouth fixation and language points to a steady and dramatic increase in period of language acquisition immediately succeeding the peak.

This relationship is less pronounced in males, for whom age predicts language pre-peak, but the role of mouth fixation is not apparent when age is no longer associated with language, post-peak. It is possible that the more subtle associations in males can be accounted for by their delayed peak in mouth fixation. As our data collection ended at the end of the second year, this only allowed for two data collection sessions (at 18 and 24 months) to occur within the "post-peak" age bracket, as opposed to three sessions for females (15, 18 and 24 months). Thus, the amount of eye tracking data is significantly reduced for the post-peak bracket in males, and is perhaps not adequately powered to address mouth fixation's role in predicting language at post-peak. Further, given the delayed mouth fixation peak in males, we would hypothesize that we may not be able to capture the full range of the post-peak decline in males that we see in females within the span of months during which we assess these infants. It is important to caution that, with this method, exploring statistical relationships among all eye tracking data collected before the peak, and all eye tracking data collected after the peak, each eye tracking session had to be treated as a separate observation, thus violating the assumption of independence, given the longitudinal nature of the data.

It is clear from the current data that a peak in mouth fixation in the second year of life seems to immediately precede and signify a shift in language development toward more substantial vocabulary learning and communicative skill. We propose two hypotheses to account for this chronological concomitance. First, mouth fixation marks the progression of an ongoing language development process, whereby an infant's interest in verbal behavior is increased. Second, mouth fixation serves as a facilitative behavior, increasing an infant's opportunity for redundant audio-visual input necessary for enhanced development of language skills. In the "indexing interest" hypothesis, visual fixation on the mouth is a behavioral marker of the ongoing process of language development, and is evident of an infant's interest in vocal behavior and the task of language acquisition. According to this hypothesis, mouth fixation indexes the increased interest in language that precedes and is predictive of the subsequent developmental step of acquiring verbal language. According to the "facilitative" hypothesis, the infant's perceptual systems are particularly attuned to stimuli that confer relevant information to supplement and enhance auditory input. It would follow that the development of language is, in part, dependent on the accumulation of such input, all of which contributes to the cognitive process of language development. In this vein of thought, just as gesture precedes and predicts language development and facilitates the step-wise process of vocabulary acquisition through increased opportunity for and experience with social and communicative interaction, mouth fixation facilitates an ongoing process through increased opportunity for exposure to language-associated stimuli.

This second hypothesis, of a facilitative role for mouth fixation in the development of language, fits well with the ideas presented by Lewkowicz and Hansen-Tift (2012), and with other research conducted in our laboratory in which eye fixation appears to play an important role in social development via increasing opportunity and exposure to stimuli important for social cognition (Jones & Klin, 2013). In keeping with the idea that preferential attention to eyes in infancy denotes increased opportunity for social learning and social cognitive development, we would posit that preferential attention to the mouth during a brief developmental period preceding language acquisition facilitates this process by expanding the opportunities for audio-visual and language-specific input and learning. It would follow that well-established sex differences in early language development might be explained by precocious shifts in attention preceding language acquisition in females.

Were this true, it could have important implications for better understanding language delay and associated disorders. Delayed language development is a hallmark of Autism Spectrum Disorders, a diagnosis with vastly different prevalence rates for males and females, affecting four males for every one female with ASD (Werling & Geschwind, 2013). In considering this sex difference in prevalence, many researchers have hypothesized mechanisms of resiliency for females, whereby those females who do develop ASD tend to be those who are more severe in symptoms, intellectual disability and genetic loading, on average, than the full range of males with the disorder. As delayed language is often an early marker, and one of the first reasons for evaluation-seeking by parents, it is possible that early developmental transitions in females, relative to males, serve some protective role, contributing to a network of early developmental pathways that amass to a mechanism of resiliency in females.

Further research should investigate the role of mouth fixation in infants with ASD and its potential function, as well as the existence of sex differences in mouth fixation and language trajectories in infancy in ASD. In approaching the hypothesis that early shift in visual attention to the mouth, along with other early developmental shifts, may be important for female resilience, research should target female infants at high risk for ASD who do not develop the disorder, and those infants who develop shadow symptoms of the disorder, to elucidate a potential role for early emergence of developmental processes for resilience.

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Appendix

Tables

Table 1
Repeated Measures ANOVA for Percent Mouth Fixation

	Full Sample Mean (SD)	**Male** Mean (SD)	**Female** Mean (SD)	**F**	***p* value**
N	50	26	24	--	--
Percent Mouth Fixation				2.938**	0.009
2 months	0.21 (0.07)	0.24 (0.04)	0.19 (0.08)		
3 months	0.19 (0.09)	0.17 (0.08)	0.21 (0.09)		
4 months	0.28 (0.12)	0.25 (0.13)	0.30 (0.11)		
5 months	0.32 (0.16)	0.31 (0.17)	0.33 (0.15)		
6 months	0.35 (0.19)	0.34 (0.21)	0.36 (0.17)		
9 months	0.42 (0.19)	0.36 (0.20)	0.50 (0.15)		
12 months	0.42 (0.19)	0.41 (0.19)	0.44 (0.19)		
15 months	0.49 (0.18)	0.42 (018)	0.56 (0.14)		
18 months	0.45 (0.15)	0.43 (0.17)	0.47 (0.12)		
24 months	0.41 (0.16)	0.39 (0.16)	0.43 (0.16)		

**. Significant at the 0.01 level (2-tailed)
*. Significant at the 0.05 level (2-tailed)

Table 2
Repeated Measures ANOVA for Measures of Language Skill and Development

	Full Sample Mean (SD)	**Male** Mean (SD)	**Female** Mean (SD)	**F**	***p* value**
$\mathbf{N_{Mullen}}$	50	26	24	--	--
Mullen[1] Visual Reception				1.055	0.377
6 months	48.63 (8.03)	48.72 (6.61)	48.54 (9.47)		
12 months	57.31 (9.20)	56.12 (9.21)	58.61 (8.38)		
18 months	53.47 (8.81)	51.32 (6.84)	55.81 (10.17)		
24 months	63.09 (8.59)	61.10 (7.77)	65.25 (9.07)		
Mullen[1] Receptive Language				2.928*	0.044
6 months	47.00 (8.06)	48.84 (6.11)	45.00 (9.47)		
12 months	45.71 (7.12)	43.68 (7.11)	47.91 (6.57)		
18 months	56.86 (12.32)	55.32 (12.90)	58.52 (11.70)		
24 months	62.86 (7.39)	61.85 (6.77)	63.95 (8.01)		
Mullen[1] Expressive Language				9.452**	<0.001
6 months	42.73 (4.54)	43.48 (3.83)	41.92 (5.16)		
12 months	45.92 (10.49)	41.68 (10.29)	50.52 (8.77)		
18 months	49.58 (10.94)	46.59 (10.81)	52.81 (10.35)		
24 months	58.68 (11.94)	53.90 (10.83)	63.85 (11.07)		
$\mathbf{N_{CDI}}$	47	24	23	--	--
MacArthur-Bates CDI Words Understands				3.739*	0.032
≤ 9 months	15.92 (19.05)	10.79 (7.32)	21.27 (25.38)		
12 months	54.53 (38.72)	44.86 (29.94)	64.62 (44.60)		
18 months	222.52 (72.88)	193.32 (59.25)	253.00 (74.39)		
MacArthur-Bates CDI Understands and Says				7.214**	0.002
≤ 9 months	0.55 (0.96)	0.47 (0.85)	0.64 (1.07)		
12 months	6.10 (5.89)	4.14 (4.65)	8.14 (6.44)		
18 months	86.10 (64.64)	56.82 (52.62)	116.65 (62.69)		
MacArthur-Bates CDI Early Gestures				3.757*	0.031
≤ 9 months	5.57 (3.49)	5.89 (3.08)	5.23 (3.92)		
12 months	10.49 (2.50)	9.64 (2.49)	11.38 (2.23)		
18 months	15.05 (2.73)	15.05 (2.03)	15.05 (3.36)		
MacArthur-Bates CDI Total Gestures				5.230**	0.009
≤ 9 months	8.35 (5.24)	8.95 (4.49)	7.73 (5.96)		
12 months	21.84 (8.10)	19.91 (7.00)	23.86 (8.81)		
18 months	45.50 (8.19)	42.68 (7.53)	48.45 (7.96)		

**. Significant at the 0.01 level (2-tailed)
*. Significant at the 0.05 level (2-tailed)
[1] Mullen measures refer to T-scores on each discrete domain of the Mullen Scales of Early Learning.

Table 3

Spearman's Correlations Pre- and Post-Peak in Females

		Mouth Fixation	CDI Und[1]	CDI Says[1]	CDI Early Gest[1]	CDI Total Gest[1]	Mullen Visual Rec[2]	Mullen Rec Lang[2]	Mullen Exp Lang[2]
Age ≤ 13.5	Age	.435**	.558**	.726**	.909**	.844**	.536**	.240	.506**
	Mouth Fixation	___	-.108	.215	.046	-.027	.024	.024	.184
Age > 13.5	Age	-.276*	.216	.218	-.377	-.022	.412	.371	.491*
	Mouth Fixation	____	-.681**	-.669**	-.068	-.507	-.120	.000	-.151

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed)

[1]CDI: Understands, Understands and Says, Early Gestures, Total Gestures

[2]Mullen: Visual Reception, Receptive Language, Expressive Language

Table 4
Spearman's Correlations Pre- and Post-Peak in Males

		Mouth Fixation	CDI Und[1]	CDI Says[1]	CDI Early Gest[1]	CDI Total Gest[1]	Mullen Visual Rec[2]	Mullen Rec Lang[2]	Mullen Exp Lang[2]
Age ≤ 15	Age	.331**	.522**	.618**	.522**	.695**	.292	-.434*	-.430*
	Mouth Fixation	——	-.010	-.110	-.118	-.116	-.109	-.003	.070
Age > 15	Age	-.002	.256	.307	.132	.128	.371	.254	.419
	Mouth Fixation	——	.280	.266	.360	.126	-.119	-.003	-.279

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)
[1]CDI: Understands, Understands and Says, Early Gestures, Total Gestures
[2]Mullen: Visual Reception, Receptive Language, Expressive Language

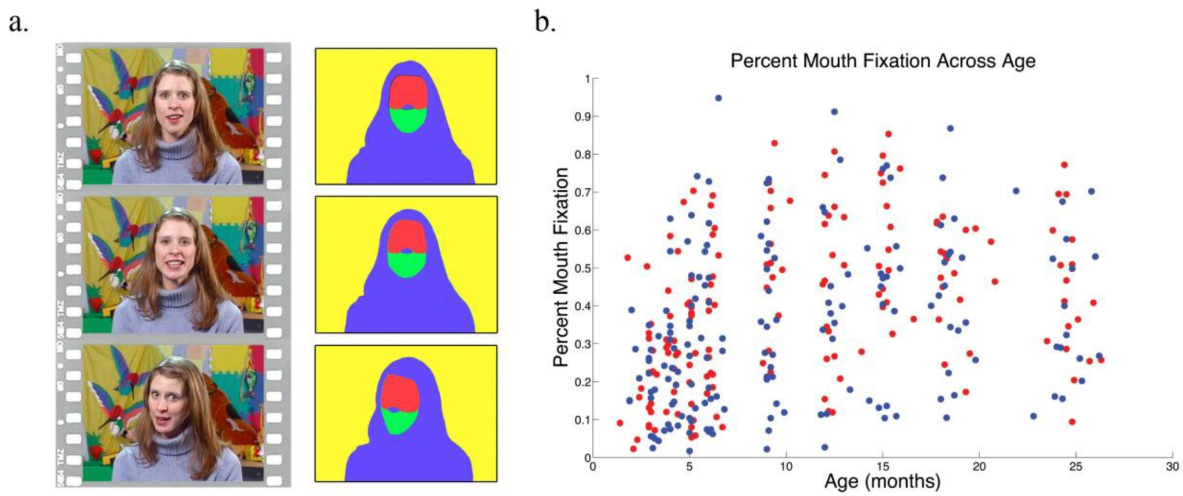
Table 5
Measure Inter-correlations in Full Sample

	Mullen Receptive Language	Mullen Expressive Language
CDI Understands	.378*	.442**
CDI Understands and Says	.383*	.594**

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)

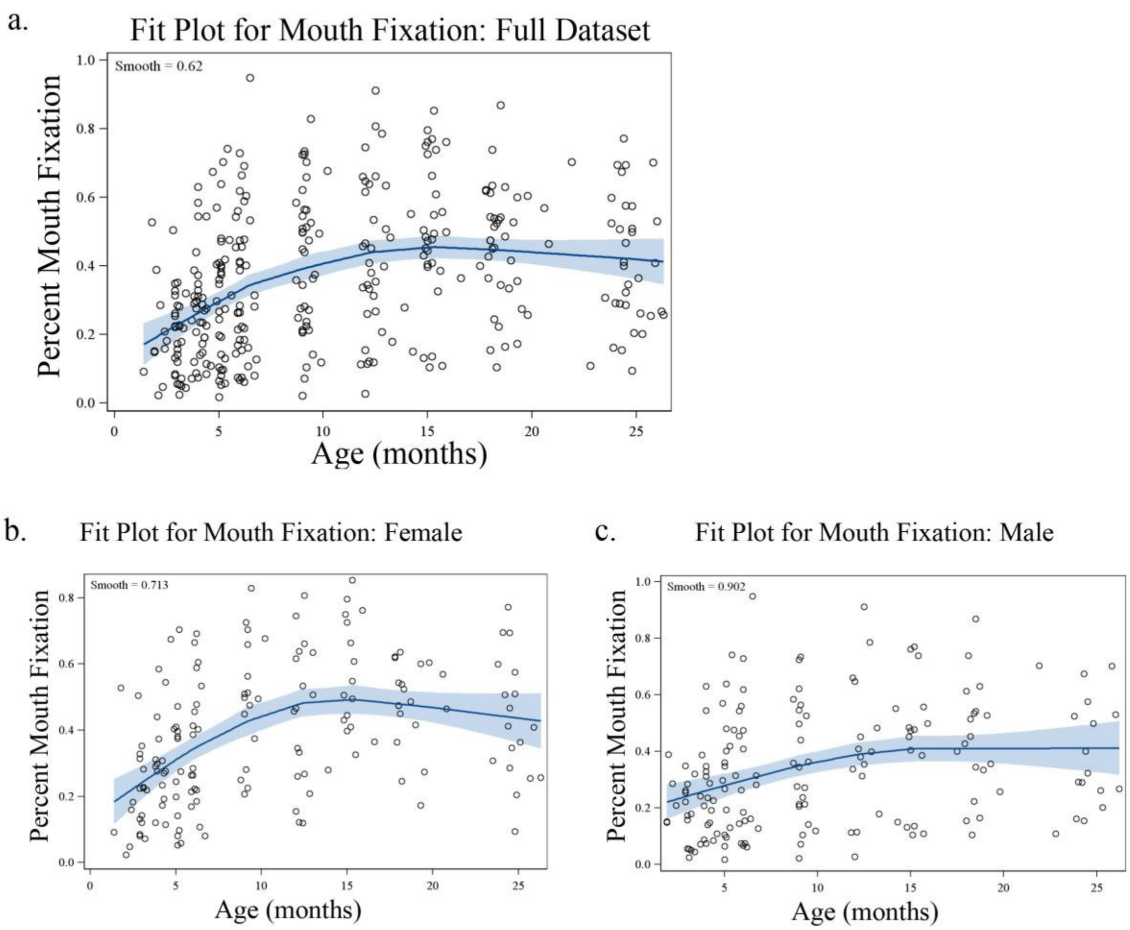
Figures

Figure 1



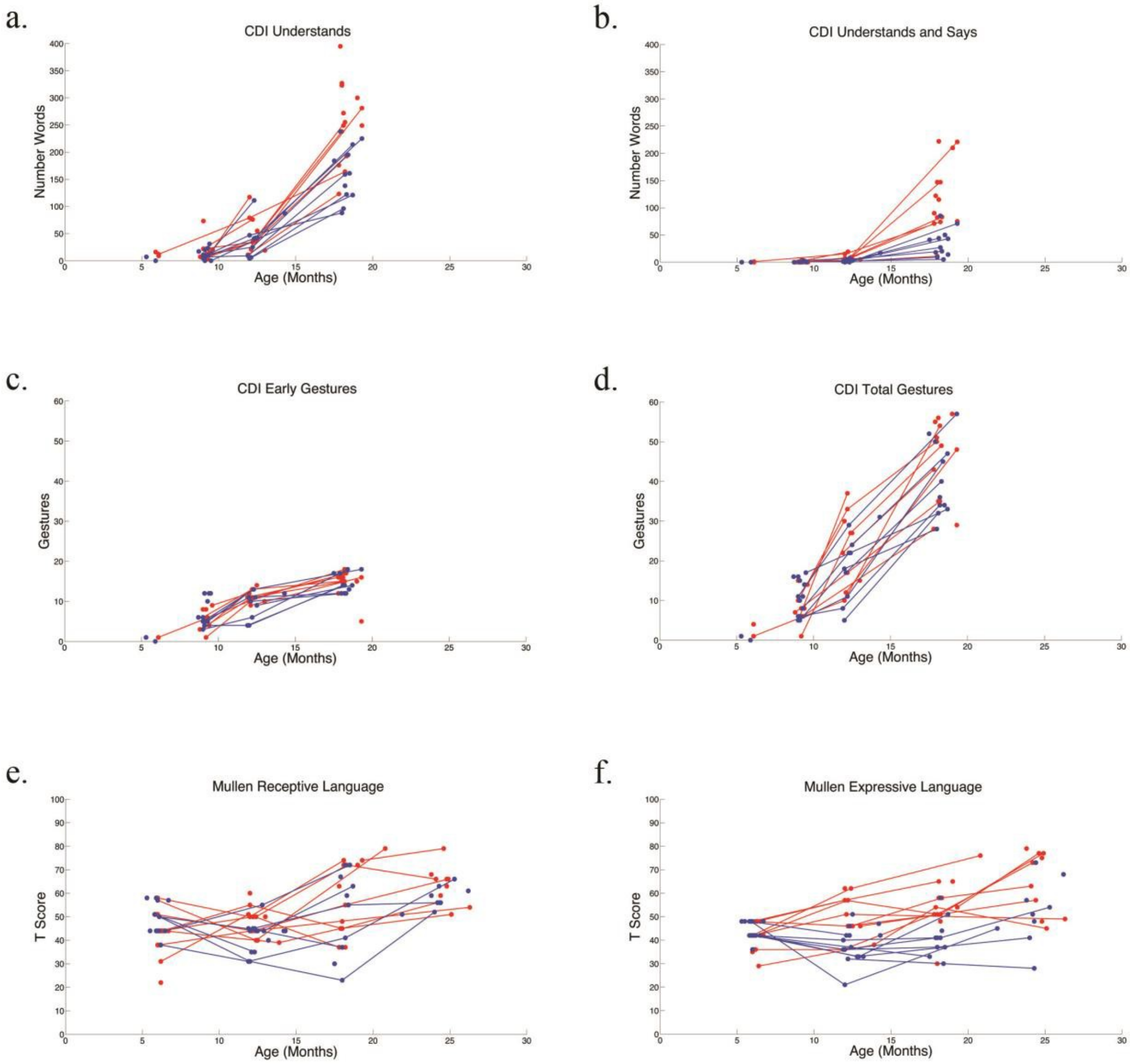
a, Representative still frames of ‘caregiver’ video clip stimuli, and corresponding regions of interest, shaded to represent eye, mouth, body, and object regions. b, Scatterplot of percent mouth fixation across age, male participants’ data in blue and female participants’ data in red.

Figure 2



Note. Shaded region indicates 95% confidence level
a, LOESS fit plot for full sample. b and c, LOESS fit plots for separated female and male samples.

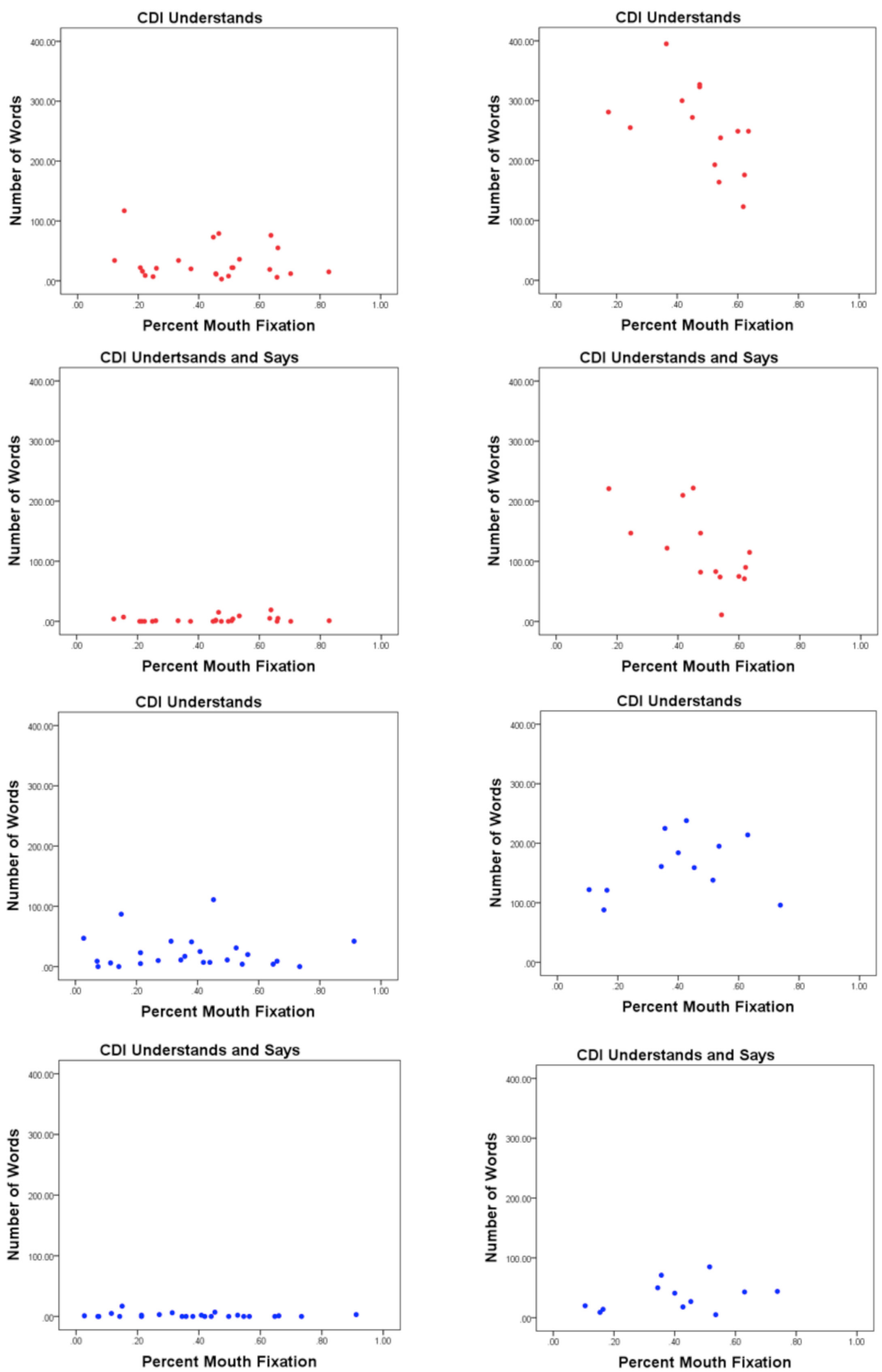
Figure 3



a, b, c, and d, Participants' trajectories of scores on indices in the MacArthur-Bates CDI, across age. e and f, Participants' trajectories of scores on scales of the Mullen, across age.

Figure 4

a. Pre-peak in mouth fixation b. Post-peak in mouth fixation



a, Scatterplots ofCDI "Understands" and "Understands and Says" indices by percent mouth fixation prior to, and encompassing, the peak in mouth fixation. b, Scatterplots of CDI "Understands" and "Understands and Says" indices by percent mouth fixation after the peak in mouth fixation. In both a and b, females are shown in red, and males in blue.