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Preference for speech in infancy differentially predicts language skills and autism-like behaviors

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Abstract

Early emerging biases for conspecific vocalizations are a hallmark of early development. Typically developing neonates listen to speech more than many other sounds including non-biological non-speech sounds but listen equally to speech and monkey calls. By 3 months, however, infants prefer speech over both non-biological non-speech sounds and over monkey calls. We examined whether different listening preferences continue to develop along different developmental trajectories and whether listening preferences are related to developmental outcomes. Given the static preference for speech over non-biological non-speech sounds and the dynamic preference for speech over monkey calls between birth and 3 months, we examined whether 9-month-olds prefer speech over non-biological non-speech sounds (Experiment 1) and speech over monkey calls (Experiment 2). We compared preferences for sounds in infants at low (SIBS-TD) and high risk (SIBS-A) of Autism Spectrum Disorder (ASD), a heterogeneous population who differ from typically developing infants in their preferences for speech, and examined whether listening preferences predict vocabulary and autism-like behaviors at 12 months for both groups. At 9 months, SIBS-TD listened longer to speech over non-speech, and monkey calls over speech, whereas SIBS-A listened longer to speech over non-speech but listened equally to speech and monkey calls. SIBS-TD's preferences did not predict immediate developmental outcomes. In contrast, SIBS-A who preferred speech to non-speech or to monkey calls had larger vocabularies and fewer markers of autism-like behaviors at 12 months, which could have positive developmental implications.

Keywords

Speech Perception and Bias; Conspecifics; Autism Spectrum Disorder

To learn language, human infants must distinguish and attend to meaningful signals among other ambient sounds. Speech may be a privileged signal for infants (Liberman & Whalen, 2000; Pinker & Jackendoff, 2005), with biases for speech contributing to infants' linguistic and social competence (Vouloumanos & Werker, 2004; 2007; Werker & Curtin, 2005).

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Indeed, infants prefer listening to speech over many types of sounds from birth. For example, neonates selectively attend to speech over filtered (Spence & DeCasper, 1987) and reversed speech (Peña et al., 2003), as well as white noise (Butterfield & Siperstein, 1970).

Whereas some speech preferences are observed throughout typically developing (TD) infants' first year, others appear to change. For example, infants consistently prefer speech over non-biological non-speech sounds from birth to 12 months (Curtin & Vouloumanos, 2013; Vouloumanos & Werker, 2004; 2007). However, when speech is compared to calls of a closely related primate species, rhesus macaques (*Macaca mulatta*), newborns listen equally to speech and monkey calls and only prefer speech to monkey calls at 3 months (Shultz & Vouloumanos, 2010; Vouloumanos, Hauser, Werker, & Martin, 2010). Similarly, hearing speech or nonhuman primate vocalizations helps 3- and 4-month-olds form object categories but, by 6 months, only speech, and not nonhuman primate vocalizations, facilitates category formation (Ferry, Hespos, & Waxman, 2013). These developmental changes suggest that conspecific (species-specific) biases are dynamic; they are initially broader and become more refined over the first few months of life (Vouloumanos et al., 2010). The dynamic changes in preference for conspecific vocalizations may be due in part to the relative familiarity or novelty of particular sounds. At birth, the considerable overlap in acoustic properties between speech and monkey calls may be perceived similarly by evolutionarily ancient biological sound processing mechanisms. By 3 months, infants may prefer speech to monkey calls because it is more familiar (e.g., Hunter & Ames, 1988; Kidd, Piantadosi, & Aslin, 2012). It is unknown however, whether older infants will prefer speech or monkey calls because conspecific biases for vocalizations have not been directly examined beyond 3 months, when novelty preferences may direct older infants' attention to unfamiliar acoustically rich sounds (e.g., Hunter & Ames, 1988; Kidd, Piantadosi, & Aslin, 2012). In the present studies, we examine whether older infants prefer speech to non-biological non-speech sounds, whether they prefer speech to monkey calls, and if either type of speech preference predicts developmental outcomes.

The contrast of speech to non-biological non-speech sounds differs from the contrast of speech to monkey calls in important ways. Monkey calls are biological vocalizations with spectral (e.g., frequency) and temporal (e.g., envelope, periodicity) characteristics that differ referentially and acoustically (Hauser & Marler, 1993; Rendall, Owren, & Rodman, 1998). These naturally produced calls allow for a direct comparison between two biologically produced vocalizations. A bias for conspecifics, rather than a general preference for speech, may serve an evolutionary function that directs infants to assign value and attend to information generated by their species (Johnson, Dziurawiec, Ellis, & Morton, 1991). Infants without species-typical preferences may have different developmental trajectories for social and linguistic skills.

Perceptual biases for speech may serve important adaptive functions (Kuhl, 1988; 1989, Vouloumanos & Werker, 2004), with stronger speech processing associated with better linguistic and social-communication skills. For example, 18-month-olds who map minimally different labels (e.g., *bin* and *din*) to novel objects have stronger vocabularies by 27 months (Kemp et al., 2016) and 7.5-month-olds who are better able to segment speech from a continuous speech stream, tend to have larger vocabularies at 24 months (Singh, Reznick, &

Xuehua, 2012). In general, TD infants who perform well on speech perception tasks that capture language-specific knowledge (e.g., discrimination of native language phonetic contrasts, words, and prosody), tend to have stronger language skills later (Cristia, Seidl, Junge, Soderstrom, & Hagoort, 2014). At the same time, TD infants who attend more to a mother's infant-directed speech at 6 months tend to show stronger joint attention skills at 12 months (Roberts, et al., 2013), suggesting speech preferences could play a role in social development.

Early conspecific biases are also important for children who develop atypically. Children with Autism Spectrum Disorder (ASD), a disorder with core deficits in social-communication skills and the presence of restricted and repetitive interests and/or behaviors (APA, 2013), do not show typical preferences for speech. For example, they listen equally, or longer to overlapping voices and sounds than to their mother's speech (Klin, 1991; 1992). However, children with ASD who prefer child-directed speech over various manipulations of speech (e.g., rotated speech, stressed speech) tend to have stronger receptive language skills (Paul, Chawarska, Fowler, Cicchetti, & Volkmar, 2007). Further, while children with ASD usually prefer non-speech to speech sounds, those who prefer speech can better detect switches between syllables (Kuhl, CoffeyCorina, Padden, & Dawson, 2005). A bias for speech may be important for linguistic and social-communication development in both TD children and children diagnosed with ASD.

The differences in listening preferences for speech between TD children and children with ASD are consistent with differences seen in neural processing for speech. For TD infants, neural responses to speech become selective within the first 4 months, with the left temporal lobe responding more to speech than non-speech sounds (Shultz, Vouloumanos, Bennett, & Pelphrey, 2014). In contrast, 2- to 3-year-olds with ASD process forward and backward speech in different brain areas than TD children (Redcay & Courchesne, 2008). Further, high functioning 10-year-olds with ASD have attenuated neural responses to speech but not complex tones, suggesting that speech encoding is impaired in this population (Whitehouse & Bishop, 2008). Indeed, these differences in neural processing persist as children with ASD become adolescents, and those with larger differences tend to have poorer spoken language (Yau, Brock, & McArthur, 2016).

Differences in individual speech preferences, and thus possible developmental differences in linguistic and social-communication skills, may emerge early in infant siblings of children diagnosed with ASD (SIBS-A), 19% of whom will receive a diagnosis by the time they are 3, compared to approximately 1.5 % in the general population (Ozonoff et al., 2011). SIBS-A may process speech differently than TD infants. As a group, SIBS-A do not prefer listening to their native language stress pattern at 5 months as low risk infants do (SIBS-TD; Ference & Curtin, 2013), and they have difficulty mapping words that differ in stress at 12 months (Ference & Curtin, 2015). However, 12-month-old SIBS-A who use lexical stress to map words have stronger expressive language at 24 months (Ference & Curtin, 2015). SIBS-A who are later found to be typically developing do not, however, always perform like SIBS-TD who are later found to be typically developing. For instance, 9-month-old SIBS-A who are later found to be typically developing, exhibit atypically large ERP responses to speech sounds, and these large responses are positively associated with later language ability (Seery,

Tager-Flusberg, & Nelson, 2014). Even though it can be useful to compare performance of SIBS-A infants with SIBS-TD, and to assume that performance of SIBS-TD represents a more optimal baseline to achieve later typical outcomes, SIBS-A may differ from SIBS-TD and still exhibit typical later outcomes.

Preferences for speech over non-biological non-speech sounds in infancy can predict later developmental outcomes differently in SIBS-A compared with SIBS-TD (Curtin & Vouloumanos, 2013; Vouloumanos & Curtin, 2014). For instance, whereas 12-month-old SIBS-A do not prefer speech as a group, individuals' relative preference for speech predicts fewer autism-like behaviors at 18 months (Curtin & Vouloumanos, 2013). In contrast, 12-month-old SIBS-TD prefer speech as a group and individuals' relative preference for speech predicts stronger expressive vocabulary at 18 months (Vouloumanos & Curtin, 2014). SIBS-A may differ in their speech preferences, leading to developmental differences in linguistic and social-communication skills.

Given the difference in stability between two kinds of speech preferences (i.e., static preference for speech over non-biological non-speech vs. dynamic preferences for speech over monkey calls) in the first three months of life, we examine the development of these preferences at 9 months. Specifically, in the current studies, we examine how 9-month-old SIBS-A and SIBS-TD attend to speech versus non-biological non-speech sounds and speech versus monkey calls. We also examine whether attending to speech relative to non-speech or monkey calls at 9 months predicts early vocabulary (as measured by the MacArthur-Bates Communicative Development Inventory; Fenson, et al., 1992) and autism-like behaviors (as measured by the Autism Observation Scale for Infants; Bryson, Zwaigenbaum, McDermott, Rombough, & Brian, 2008) at 12 months. We explored relationships within groups separately because while SIBS-TD and SIBS-A differ in the variability of their later developmental outcomes, there can be considerable overlap between the two groups. A subset of SIBS-A will later be diagnosed with ASD themselves, with additional subsets being diagnosed with developmental delays, or subclinical features of ASD known as the broader autism phenotype, however, approximately half of SIBS-A will develop typically (Jones, Gliga, Bedford, Charman, & Johnson, 2014; Ozonoff et al., 2011; 2014). Given this variable range of developmental outcomes among SIBS-A and the overlap in outcomes between the two groups, we did not predict group differences between SIBS-A and SIBS-TD at 9 months.

Experiment 1: Speech vs Non-Speech Method

Participants

Participants were 99 (46 females) 9-month-old infants from English-speaking homes, who were part of a larger study (for demographic information see Table 1). An additional 42 infants (24 SIBS-TD and 18 SIBS-A) were excluded due to experimenter error in ending the trials ($n = 23$), programming error ($n = 12$) or dropping out of the study ($n = 7$). The sample size was based on previous studies with large effect sizes and power of 0.80 at alpha level $p < .05$ ($f^2_{\text{speech preference index}} = 0.54$) in TD infants. Given that SIBS-A differ from SIBS-TD in listening preferences for speech, we reasoned that such an effect for speech might be attenuated, thus we recruited a large enough sample from this rare population to detect a

speech preference of medium effect (for power of 0.80, with an alpha level of $p < .05$, we required $n = 55$ in each group tested separately). Racial distribution was: 81% White, 16% multiracial, and 2% Asian. Seventy-one percent of infants heard English only in their homes and 29% heard one or more languages in addition to English. Parents reported how much English their infants heard on a 3 point-scale: 1. We always talk to him/her in English. 2. We sometimes talk to him/her in English. 3. We rarely talk to him/her in English. For LR infants: Always: 22 of 23 infants; Sometimes: 1 of 23; Rarely: 0 of 23. For HR infants: Always: 14 of 18; Sometimes: 4 of 18; Rarely: 0 of 18. All participants were healthy, full-term infants with at least one older sibling. SIBS-TD ($n = 60$; 28 females) were recruited from maternity wards at local hospitals and through local parent fairs, flyers, and advertisements. Parents of SIBS-TD completed a questionnaire to ensure that immediate family members did not present with ASD. All SIBS-A ($n = 39$; 18 females) had at least one older sibling diagnosed with ASD (3 infants had 2 older diagnosed siblings) by a community pediatrician or psychologist, and were recruited through local pediatric clinics and autism organizations. Household income did not differ between the groups (Mann-Whitney $U = 931.5$, $p = .22$), however, maternal education differed marginally (Mann-Whitney $U = 879.5$, $p = .06$; Maternal education and household income were ranked ordinally (1–8th grade and \$20,000/year, and 9–professional degree and \$200,000/year; See Table 1). Exclusionary criteria included the presence of a neurological disorder of known etiology, significant sensory or motor impairment, major physical abnormalities, and history of serious head injury and/or neurological disease. Parents gave informed consent on behalf of their infants and received either \$20 at each visit or a \$100 bonus at the final visit. Parents also received a certificate and small toys or t-shirts as gifts. All procedures were approved by the IRB (Site 1: IRB-FY 2016–170, Site 2: REB15–1002).

Stimuli

Stimuli were the sounds used in Vouloumanos & Werker (2004).

Pretest and posttest music.—Immediately before and after experimental testing, infants heard a 40 s clip of Bach's Concerto for Violin and Orchestra No 1 in A minor (BWV 1041-III. Allegro Assai). The pretest familiarized infants with the procedure and the posttest allowed us to assess infants' attention (e.g., Cooper & Aslin, 1994; Vouloumanos & Werker, 2004).

Speech.—Human speech stimuli consisted of monosyllabic nonsense words spoken by a female native English speaker. The 12 distinct tokens (six 'lif' tokens and six 'neem' tokens) varied in intonational contour (average minimum and maximum pitch: 197 Hz and 350 Hz) and duration (525–1155 ms).

Non-biological non-speech.—Non-speech sounds consisted of time varying sinusoidal waves tracking the main regions of significant energy, specifically the fundamental frequency and the first three formants of speech. These non-speech sounds reproduce the main spectral and temporal changes in natural speech, retaining the duration, pitch contour, amplitude envelope, relative formant amplitude, and relative intensity of speech counterparts. However non-speech sounds differed from speech in: 1) voice quality (non-

speech analogues have none), 2) naturalness or biological quality (non-speech analogues are artifacts), and 3) characteristics of the source (speech has one source, the vocal tract, while non-speech analogues have four, one per sinusoidal tone). (For a complete description of stimulus creation, see Vouloumanos, Kiehl, Werker & Liddle, 2001; Vouloumanos & Werker, 2004).

Procedure

Infants were tested using an infant-controlled sequential preferential looking procedure (e.g., Cooper & Aslin, 1990; Vouloumanos & Werker, 2004) during which infants controlled trial onset and offset by looking at or away from a central monitor displaying a bullseye. Testing was conducted in a sound-attenuated room with sounds played at average amplitude of 60 dB (± 5 dB). During testing, infants sat on a parent's lap 35" (89 cm) in front of a 30" (76.25 cm) computer monitor. Infants' attention was drawn to the monitor by a flashing red light at the beginning of the experiment and before each trial. Once the infant fixated on the monitor, a stationary bullseye appeared in tandem with one set of sounds, either speech or non-speech. When the infant looked away from the monitor for 2 consecutive seconds, presentation of the sounds and visual display ceased. The infant's attention was drawn back to the monitor by the flashing red light and the other set of sounds was presented. Three trials for each speech and nonspeech were presented in random order, with no more than two sequential trials of the same sound type. We compared infants' looking time to the screen during speech and non-speech by using frame-by-frame offline coding (30 frames per s) by coders blind to the type of experimental trial. To ensure reliability of the data, a second coder coded 20% of trials for each video. Intraclass correlation coefficient was 0.98, $p < .001$.

Observational Measures

To ensure our groups did not differ in early cognitive development, at 12 months, infants were administered the Mullen Scales of Early Learning (MSEL; Mullen, 1995). There were no differences between groups on the MSEL Early Learning Composite, a standardized score of general cognitive development ($t(89) < 1$; See Table 1).

At 12 months, infant vocabulary was assessed using the MacArthur-Bates Communicative Development Inventory: Words and Gestures form (MB-CDI; Fenson, et al., 1992). The MB-CDI is a parent report scale of early language competence, which has been standardized on 659 children, aged 8 to 16 months (Feldman, et al., 2000). The Words and Gestures form of the MB-CDI assesses infant understanding of phrases, vocabulary production and comprehension, use of gestures, engagement in games/routines, imitation, and actions made with objects. At 12 months, the risk groups did not differ on percentiles of Words Understood or Produced (t 's (86) < 1.5 ; See Table 1). The MB-CDI scores for these infants were comparable to previous research (e.g., Mitchell et al., 2006) and given the significant positive correlations between the two scales (Words Understood and Words Produced, $r = .44$, $p < .001$), parental reports appeared consistent.

At 9 and 12 months, autism-like behaviors were assessed using the Autism Observation Scale for Infants (AOSI; Bryson, et al., 2008). The AOSI is an interactive, observational

measure that assesses aspects of social communication, social interaction, attention, play, and sensorimotor functions that are known to be atypical in children with ASD (Zwaigenbaum et al., 2005). The AOSI was developed to detect and monitor early signs of ASD in SIBS-A and requires an examiner to administer a standard set of semi-structured activities that systematically press for particular target behaviors. These behaviors are then rated on a scale of 0 to 3, with higher scores indicating a deviation from typical behavior (Bryson, et al., 2008). Adding the ratings from all 18 items derives a total score and adding together the number of items scored between 1 and 3 indicates a total markers score. The total score can thus be thought of as an indicator of severity and the total markers can be thought of as the breadth of symptom expression. The AOSI has excellent inter-rater reliability (e.g., 0.94 at 18 months) and fair to good test-retest reliability (e.g., 0.61 at 12 months; Bryson, et al., 2008). A total score of 9 or more at 12 months on the AOSI has been found to be predictive of an independent, blind, “gold standard” ASD diagnosis at 36 months (Bryson, et al., 2008). The AOSI was administered and coded by a trained examiner. A second coder coded 10% of administrations. Intraclass correlation coefficient (ICC) for total score was .88, $p < .001$, and for total markers was .64 ($p < .05$). ICCs at 9 months were AOSI total score (.95) and total markers (.65), and at 12 months were AOSI total score (.76) and total markers (.63). At 9 months, the risk groups did not differ on AOSI Total Scores or AOSI Total Markers ($t(97) < 1.5$; See Table 1). However, at 12 months the groups differed marginally (AOSI Total Score: $t(92) = 1.79$, $p = .08$; AOSI Total Markers; $t(92) = 1.81$, $p = .08$; See Table 1).

Complete sets of items for MSEL, MB-CDI, and AOSI are available via the publicly accessible National Database for Autism Research (<https://ndar.nih.gov/>).

Results

We examined whether SIBS-A and SIBS-TD preferred speech to non-biological non-speech sounds at 9 months, and whether individual speech preferences predicted later vocabulary and autism-like behaviors. Given the intrinsic heterogeneity of SIBS-A, and the overlapping distribution in typical outcomes between groups (Jones, Gliga, Bedford, Charman, & Johnson, 2014; Ozonoff et al., 2011; 2014) and based on previous research examining speech perception in SIBS-A (e.g., Ference & Curtin, 2015; Curtin & Vouloumanos, 2013), we did not expect group differences. As such, we conducted separate parametric tests to examine within-group differences in speech preference in addition to testing for group differences. We then examined how individuals' speech preference predicted later vocabulary using the MB-CDI, and autism-like behaviors using the AOSI.

Overall preference for speech

Overall, infants listened significantly longer to speech than non-speech at 9 months. A 2 (risk group: SIBS-TD, SIBS-A) $\times$ 2 (sound type: speech, non-speech) $\times$ 3 (trial: 1, 2, 3) mixed-model Analysis of Variance (ANOVA; SPSS version 22.0, IBM Corp., 2013) revealed a significant main effect for sound type, $F(1, 96) = 8.55$, $p = .004$, $\eta^2 = .01$. (We tested for differences between the two sites by including site as a factor in the mixed-model Analysis of Variance, however, no relevant effects were found so we collapsed across site for all

subsequent analyses.) Risk group and sound type did not interact suggesting that SIBS-A and SIBS-TD listened similarly to speech and nonspeech, $F(1,96) = 0.11, p = .74, \eta^2 = .00$. SIBS-TD as a group listened longer to speech ($M_{speech} = 10.7$ s, $SD = 5.5$) than non-speech ($M_{non-speech} = 9.3$ s, $SD = 5.4$; $t(59) = 2.12, p = .04$). SIBS-A also listened longer to speech ($M_{speech} = 12.5$ s, $SD = 5.9$) than to nonspeech ($M_{non-speech} = 10.7$ s, $SD = 5.0$; $t(37) = 2.02, p = .05$; See Figure 1 for individual infants' relative looking time for speech compared to non-speech.) There were no group differences in mean looking time to the pre-test or the post-test ($t's(96) < 1$; See Table 1).

Predicting developmental outcomes from speech versus non-speech preference

Next, we calculated a Speech Preference Index for each participant by subtracting mean looking time during non-speech trials from mean looking time during speech trials. A positive score reflects a preference for speech while a negative score reflects a preference for non-speech. We used linear regressions to examine whether a relative preference for speech over non-speech at 9 months predicted later receptive and expressive language on the MB-CDI at 12 months and severity and breadth of autism-like symptoms as measured by AOSI Total Scores and AOSI Total Markers at 12 months. Additional covariates in the latter two models were AOSI Total Scores at 9 months and AOSI Total Markers at 9 months. We mean centered all continuous predictor variables. (See Table 2 for correlations among predictor variables).

Predicting vocabulary from speech versus non-speech preference between groups

Speech Preference Index at 9 months and risk group did not predict receptive language at 12 months ($R^2 = .03, F(1,86) = 2.33, p = .13$; ($R^2 = .02, F(2,85) = 2.16, p = .22$). However, Speech Preference Index and risk group marginally interacted suggesting that the relationship between attention to speech and receptive language may differ for each risk group ($R^2 = .03, F(3,84) = 2.32, p = .08$). Speech Preference Index at 9 months, risk group, and the interaction of speech preference index and risk group did not predict expressive language at 12 months ($R^2 = .01, F(1,86) = .90, p = .35$; $R^2 = .01, F(2,85) = 1.05, p = .35$; $R^2 = .01, F(3,84) = .94, p = .43$; See Table 3 for complete model results).

Predicting vocabulary from speech versus non-speech preference within groups

SIBS-A who listened longer to speech over non-speech when they were 9 months old understood ($R^2 = .11, F(1,34) = 4.35, p = .05$) but did not produce more words at when they were 12 months ($R^2 = .05, F(1,34) = 1.65, p = .21$). For SIBS-TD, there was no relationship between Speech Preference Index at 9 months and amount of words infants understood at 12 months ($R^2 = .00, F(1,50) = 0.00, p = .99$) or produced ($R^2 = .00, F(1,50) = 0.01, p = .92$; see Table 5 for complete model results and Figure 2 for scatterplots of Speech Preference Index on Words Understood and Words Produced for each risk group).

Predicting behaviors characteristic of autism from speech versus non-speech between groups

Speech Preference Index at 9 months, risk group, and the interaction of speech preference index and risk group all predicted AOSI Total Score at 12 months suggesting that the

relationship between attention to speech and autism-like symptoms may differ for each risk group ($R^2 = .04$, $F(1,92) = 4.17$, $p = .04$; $R^2 = .04$, $F(2,91) = 4.00$, $p = .02$ $R^2 = .02$, $F(3,90) = 3.42$, $p = .02$; See Table 4 for complete model results). Speech Preference Index at 9 months did not predict AOSI Total Markers at 12 months ($R^2 = .03$, $F(1,92) = 2.92$, $p = .09$), however, risk group and the interaction of risk group and Speech Preference Index predicted AOSI Total Markers at 12 months suggesting that the relationship between attention to speech and autism-like symptoms is different for the two risk groups ($R^2 = .04$, $F(2,91) = 3.34$, $p = .04$; $R^2 = .05$, $F(3,90) = 3.21$, $p = .03$; See Table 4 for complete model results).

Predicting behaviors characteristic of autism from speech versus non-speech preference within groups

SIBS-A who listened longer to speech than non-speech when they were 9 months old had marginally lower AOSI Total scores ($R^2 = .20$, $R^2 = .08$, $F(1,34) = 3.46$, $p = .072$) and AOSI Marker scores ($R^2 = .20$, $R^2 = .09$, $F(1,34) = 3.92$, $p = .056$) when they were 12 months old. However, for SIBS-TD, Speech Preference Index did not predict AOSI Total Scores ($R^2 = .06$, $R^2 = .00$, $F(1,54) = 0.13$, $p = .72$) or AOSI Total Markers ($R^2 = .05$, $R^2 = .00$, $F(1,54) = 0.00$, $p = .99$). See Table 6 for complete model results and Figure 3 for scatterplots of Speech Preference Index on AOSI Total Scores and AOSI Total Markers for each risk group).

Experiment 2: Speech vs Monkey Calls Method

Participants

Participants were 100 (50 females) 9-month-old infants from English-speaking homes, a subset of whom participated in Experiment 1 (for demographic information see Table 1). An additional 40 infants (29 SIBS-TD and 10 SIBS-A) were excluded due to fussiness ($n = 2$), experimenter error in ending the trials ($n = 26$), programming error ($n = 4$), dropping out of the study ($n = 5$), or failing to look away from the stimulus monitor during the entire testing period ($n = 3$). The sample size was determined as for Experiment 1: to detect a speech preference of medium effect (for power of 0.80, with an alpha level of $p < .05$, we required $n = 55$ in each group tested separately). Racial distribution was: 83% White, 15% multiracial, and 2% Asian. Seventy-two percent of infants heard English only in their homes and 28% heard one or more languages in addition to English. Parents reported how much English their infants heard on a 3 point-scale: 1. We always talk to him/her in English. 2. We sometimes talk to him/her in English. 3. We rarely talk to him/her in English. For LR infants: Always: 22 of 24 infants; Sometimes: 2 of 24; Rarely: 0 of 24. For HR infants: Always: 17 of 21; Sometimes: 4 of 21; Rarely: 0 of 21 infants. All participants were healthy, full-term infants with at least one older sibling and were recruited and excluded as in Experiment 1. SIBS-TD ($n = 54$; 27 females) had no first degree relatives diagnosed with ASD and SIBS-A ($n = 46$; 23 females) had at least one older sibling diagnosed with ASD (3 infants had 2 older diagnosed siblings). Household income did not differ between the groups (MannWhitney $U = 993.5$, $p = .20$), however, maternal education did (Mann-Whitney $U = 935$, $p = .03$; Maternal education and household income were ranked ordinally (1 8th grade and \$20,000/year, and 9 professional degree and \$200,000/year; See Table 1). Parents gave

informed consent and were compensated as in Experiment 1. All procedures were approved by the IRB (Site 1: IRB-FY 2016–170) and (Site 2: REB15–1002).

Stimuli

Sounds were human speech tokens and rhesus monkey calls used in Vouloumanos et al. (2010). Sound duration did not differ, but monkey calls naturally exhibit a slightly higher pitch, $t(17) = 2.3$, $p < .05$.

Pretest and posttest music.—Identical to Experiment 1.

Speech.—Human speech stimuli consisted of ten nonsense speech tokens produced in infant-directed speech by three native English-speaking females (Speaker 1: “ploo”, “keev”, “yut”, “boola”, “nahod”, “kraw”; Speaker 2: “trom”, “fi”; Speaker 3: “dup”, “makalak”). Speech tokens varied in pitch ($M = 283$ Hz) and duration ($M = 468$ ms).

Monkey Calls.—Monkey calls consisted of ten distinct calls produced by three female rhesus monkeys (*Macaca mulatta*; Caller 1: 3 social or food related coos and 3 affiliative girneys; Caller 2: 1 coo and 1 food related warble; Caller 3: 1 coo and 1 girney). Monkey calls were recorded on Cayo Santiago, Puerto Rico, using a highly directional shotgun microphone at a distance of 1–3 m. We used monkey calls produced during positive social and resource contexts, excluding calls produced during aggressive and copulatory contexts as human neonates listen less to angry or sad voices (Aldridge, 1994, as cited in Walker-Andrews, 1997; Hauser, 2000). Monkey calls varied in pitch ($M = 346$ Hz) and duration ($M = 531$ ms).

Procedure

The procedure of Experiment 2 was identical to Experiment 1 except using speech and monkey calls. As in Experiment 1, we compared infants' looking time during speech and monkey calls using frame-by-frame offline coding (30 frames per s) by coders blind to experimental trial. To ensure reliability, a second coder coded 20% of trials for each video. Intraclass correlation coefficient was 0.99, $p < .001$.

Observational Measures

Groups did not differ on the MSEL Early Learning Composite, a standardized score of general cognitive development at 12 months, ($t(90) < 1$; See Table 1).

At 12 months, the risk groups did not differ on percentiles of Words Understood or Produced on the MB-CDI Words and Gestures form (t 's (89) < 1 ; see Table 1; Fenson, et al., 1992). The MB-CDI scores for these infants were comparable to previous research (e.g., Mitchell et al., 2006) and given the significant positive correlations between the two scales (Words Understood and Words Produced, $r = .40$, $p < .001$), parents appeared consistent in reporting their infant's vocabulary.

At 9 and 12 months, autism-like behaviors were assessed using the AOSI (Bryson, et al., 2008) by a trained examiner. A second coder coded 10% of administrations. Intraclass

correlation coefficient for total score was .88, $p < .001$, and for total markers was .64 ($p < .05$). At 9 months, the risk groups marginally differed on AOSI Total Scores ($t(98) = 1.82$, $p = .07$) and AOSI Total Markers ($t(98) = 1.84$, $p = .07$). However, at 12 months they did not t 's (94) < 1.4 ; See Table 1).

Results

We examined whether SIBS-A and SIBS-TD preferred conspecific vocalizations at 9 months, and whether individual preferences predicted later vocabulary and autism-like behaviors. As in Experiment 1, we examined differences in SIBS-A separately from SIBS-TD by conducting separate parametric tests to examine within-group differences in speech preference in addition to testing for group differences. We then examined how individuals' conspecific preference predicted vocabulary using the MB-CDI, and autism-like behaviors using the AOSI.

Overall preference for speech

Overall, infants listened significantly longer to monkey calls than to speech at 9 months. A 2 (risk group: SIBS-TD, SIBS-A) $\times$ 2 (sound type: speech, monkey call) $\times$ 3 (trial: 1, 2, 3) mixed-model ANOVA (SPSS version 22.0, IBM Corp., 2013) revealed a significant main effect for sound type, $F(1, 98) = 4.41$, $p = .038$, $\eta^2 = .01$. (As in Experiment 1, no effects of site were found so we collapsed across site for all subsequent analyses.) Risk group and sound type did not interact suggesting that SIBS-A and SIBS-TD listened similarly to speech and monkey calls, $F(1, 98) = 0.75$, $p = .39$, $\eta^2 = .00$. SIBS-TD as a group listened longer to monkey calls ($M_{monkey} = 18.7$ s, $SD = 8.7$) than speech ($M_{speech} = 16.6$ s, $SD = 9.5$; $t(53) = 2.26$, $p = .03$). SIBS-A as a group listened equally to the sounds, ($M_{monkey} = 19.7$ s, $SD = 9.1$, $M_{speech} = 18.8$ s, $SD = 9.4$; $t(45) = .81$, $p = .42$; See Figure 1 for individual infants' relative looking time for speech compared to monkey calls.) There were no group differences in mean looking time to the pre-test or the post-test (t 's (98) < 1.3 ; See Table 1).

Predicting developmental outcomes from speech versus monkey preference

As in Experiment 1, we calculated a Speech Preference Index for each participant by subtracting mean looking time during monkey trials from mean looking time during speech trials. A positive score reflects a preference for speech while a negative score reflects a preference for monkey calls. We then used linear regressions to examine whether a relative preference for speech over monkey calls at 9 months of age predicted later receptive and expressive language as measured by the standardized percentiles of the Words Understood and Words Produced on the MB-CDI at 12 months and severity and breadth of autism-like symptoms as measured by AOSI Total Scores and AOSI Total Markers at 12 months. Additional covariates in the latter two models were AOSI Total Scores at 9 months and AOSI Total Markers at 9 months. We mean centered all continuous predictor variables (See Table 2 for correlations among predictor variables).

Predicting vocabulary from speech versus monkey preference between groups

Speech Preference Index at 9 months, risk group, and the interaction of Speech Preference Index and risk group did not predict receptive language at 12 months ($R^2 = .00$, $F(1, 87) = .$

13, $p = .72$; $R^2 = .00$, $F(2,86) = .07$, $p = .35$; $R^2 = .90$, $F(3,85) = .94$, $p = .44$; See Table 3 for complete model results). Speech Preference Index at 9 months, risk group, and the interaction of Speech Preference Index and risk group did not predict expressive language at 12 months ($R^2 = .02$, $F(1,87) = 1.78$, $p = .19$; $R^2 = .01$, $F(2,86) = 1.23$, $p = .30$; $R^2 = .05$, $F(3,85) = 1.64$, $p = .19$; See Table 3 for complete model results).

Predicting vocabulary from speech versus monkey preference within groups

SIBS-A who listened longer to speech over monkey calls when they were 9 months old produced marginally more ($R^2 = .09$, $F(1,40) = 3.73$, $p = .06$) but did not understand more words when they were 12 months old ($R^2 = .04$, $F(1,40) = 1.72$, $p = .20$). For SIBS-TD, there was no relationship between Speech Preference Index at 9 months and the number of words infants understood at 12 months ($R^2 = .02$, $F(1,45) = 0.90$, $p = .35$) or produced ($R^2 = .00$, $F(1,45) = 0.08$, $p = .79$; see Table 5 for complete models results and Figure 4 for scatterplots of Speech Preference Index on Words Understood and Words Produced for each risk group).

Predicting behaviors characteristic of autism from speech versus monkey preference between groups

Speech Preference Index at 9 months, risk group, and the interaction of Speech Preference Index and risk group did not predict AOSI Total Score at 12 months ($R^2 = .00$, $F(1,94) = .23$, $p = .63$; $R^2 = .02$, $F(2,93) = .92$, $p = .40$; $R^2 = .04$, $F(3,92) = 2.02$, $p = .17$; See Table 4 for complete model results). Neither Speech Preference Index at 9 months nor risk group predicted AOSI Total Markers at 12 months ($R^2 = .00$, $F(1,94) = .29$, $p = .59$; $R^2 = .03$, $F(2,93) = 1.17$, $p = .32$), however the interaction of risk group and Speech Preference Index marginally predicted AOSI Total Markers at 12 months suggesting that the relationship between attention to speech and autism-like symptoms is different for the two risk groups ($R^2 = .05$, $F(3,92) = 2.51$, $p = .06$; See Table 4 for complete model results).

Predicting behaviors characteristic of autism from speech versus monkey preference within groups

SIBS-A who listened longer to speech than monkey calls when they were 9 months old had marginally lower AOSI Total scores ($R^2 = .20$, $R^2 = .08$, $F(1,41) = 3.89$, $p = .055$) and significantly lower AOSI Marker scores ($R^2 = .18$, $R^2 = .10$, $F(1,41) = 4.83$, $p = .03$) when they were 12 months old. However, for SIBS-TD, Speech Preference Index did not predict AOSI Total Scores ($R^2 = .07$, $R^2 = .03$, $F(1,49) = 1.71$, $p = .20$) or AOSI Total Markers ($R^2 = .09$, $R^2 = .04$, $F(1,49) = 2.11$, $p = .15$). See Table 6 for complete model results and Figure 5 for scatterplots of Speech Preference Index on AOSI Total Scores and AOSI Total Markers for each risk group).

For all predictive analyses, we checked the assumptions of regression. No data points were identified as overly influential (i.e., outlier).

General Discussion

Nine-month-old SIBS-TD preferred listening to speech over non-biological nonspeech sounds and monkey calls over speech; however, these preferences did not predict vocabulary or autism-like behaviors at 12 months. SIBS-A patterned differently from this reference group, as they preferred listening to speech over non-speech but listened equally to speech and monkey calls (although the interaction between speech preference and risk group did not always reach the alpha of .05). SIBS-A who preferred speech, either when compared with non-biological non-speech or when compared with monkey calls, had larger vocabularies and fewer indicators of autism-like behaviors at 12 months (though some effects, for example the effect of the speech vs. monkey call preference on Words Produced and the effect of the speech vs. non-speech preference on AOSI Total Markers did not reach statistical significance at an alpha of .05), compatible with a possible protective role of biases for conspecific vocalizations in SIBS-A.

Our results show that at 9 months TD infants prefer monkey calls when contrasted with speech but maintain their preference for speech when it is contrasted with non-biological non-speech sounds (Curtin & Vouloumanos, 2013; Vouloumanos & Werker, 2007; 2004). It is possible that older TD infants are flexible in their attention to speech, shifting depending on the context in which speech is presented. Indeed, contrasting speech with different sounds may differentially engage mechanisms that bias people to attend to and assign value to conspecific information in voices and faces (Johnson et al., 1991). TD infants might always prefer speech to non-biological, nonspeech sounds that do not engage evolutionarily ancient biological sound processing mechanisms (e.g., Curtin & Vouloumanos, 2013; Vouloumanos & Curtin, 2014). But when speech and monkey calls are both available, TD infants may change their listening preferences depending on the value they assign to the sounds (Johnson et al., 1991) and the functions of the different vocalizations. For example, newborns may attend to both speech and monkey calls because they share acoustic features (Vouloumanos, et al., 2010). But by 3 months, TD infants may have come to link speech with people (Legerstee, Barna, & DiAdamo, 2000; Vouloumanos, Druhen, Hauser, & Huizink, 2009) and attend to it because of its emotional or informational content. By 9 months, TD infants might prefer monkey calls because they have the potential to provide new information.

A change in the role that vocalizations play for infants has also been proposed to explain infants' shifting preference for infant-directed speech compared with adult-directed speech in the first year. While 4-month-olds prefer infant-directed speech, this preference disappears at 7–9 months, and then re-emerges at 10 months (Hayashi, Tamekawa, & Kiritani, 2001; c.f. Frank et al., 2017). Hayashi et al. speculate a changing role for infant-directed speech, initially for emotional attachment and then for learning language. Shifting listening preferences in the first year might reflect changes in how different vocalizations satisfy infants' evolving needs for linguistic and social-communication development.

Similarly, infants preferentially attend to and learn better from some vocalizations compared with others, specifically, native as opposed to non-native speakers or native accented speakers (Kinzler, Dupoux, & Spelke, 2007; Marno et al., 2016). In those cases, the more

familiar, native speech may help infants learn and form one basis for social categorization (Kinzler et al., 2007). In the present studies, older TD infants listened more to monkey calls than to speech perhaps because monkey calls are more novel compared to speech, with which they have had much more perceptual experience. This suggestion is consistent with the pattern of infants' preferences for auditory and visual stimuli shifting towards novelty with age or exposure (Hunter & Ames, 1988; Kidd, Piantadosi, & Aslin, 2012). Monkey calls may thus have the potential to provide new information for infants but this information does not contribute to their social-communication and linguistic development (which may explain the lack of predictive relationships for later language and social measures). Thus biological, primate vocalizations may play different roles for infants of different ages, which may help explain why older infants do not always prefer speech.

As in prior studies comparing speech to non-biological non-speech sounds, SIBS-A did not prefer speech over monkey calls at 9 months. This lack of group preference may stem from the heterogeneous nature of the SIBS-A group who will experience a range of developmental outcomes. By 36 months about 19% of SIBS-A will be diagnosed with ASD, with an additional 28% developing atypically (e.g., with delays in language and/or cognitive skills), leaving 54% that are developing typically (Ozonoff et al., 2014). Moreover, even among children diagnosed with ASD, there is considerable variance in speech preferences (e.g., Kuhl et al., 2005). Analyses of SIBS-A in the aggregate may have concealed sub-group effects and longitudinal analyses are needed to test this possibility. However, the regression analyses revealed important potential individual differences: SIBS-A who preferred listening to speech over monkey calls at 9 months demonstrated stronger vocabulary scores and fewer markers of autism-like behaviors at 12 months. These findings suggest that early attention to speech in high-risk infants who demonstrate early indicators of typical development, does not necessarily map onto the developmental trajectory of TD infants. For high-risk infants, attention to speech may serve a different purpose at different points in development than it does for TD infants.

The infants within the SIBS-A group who preferred speech over non-biological non-speech (Experiment 1) and over monkey calls (Experiment 2) at 9 months had larger vocabularies and fewer autism-like behaviors at 12 months (though some effects did not reach statistical significance at an alpha of .05, for example, speech vs. monkey call preference on Words Produced, and speech vs. non-speech preference on AOSI Total Markers). These findings may suggest that the emergence of speech preferences is differently timed in our two risk groups. Although some effects were marginal, results were consistent across both studies (see bolded R² for SIBS-A in Tables 3 and 4). SIBS-A might require additional maturation or exposure to language for their conspecific preferences to emerge. Developmental differences in timing in at risk populations is also seen in how infants perceive native and non-native speech contrasts. By 10 months, TD infants no longer readily discriminate non-native speech contrasts (Werker & Tees, 1984). However, infants born 12 weeks premature still discriminate non-native contrasts, suggesting they need additional time and/or experience with their native language (Peña, Werker, & Dehaene-Lambertz, 2012). Similarly, infants of depressed mothers exposed to selective serotonin reuptake inhibitors prenatally do not discriminate non-native contrasts at 6 or 10 months, while non-exposed infants of depressed mothers continue to discriminate at 10 months (Weikum, Oberlander,

Hensch, & Werker, 2012). Thus, age alone is not sufficient to identify when a shift in perception can occur, and the consequences this shift may have on development. Given the shift in SIBS-TD's preferences for heterospecific over conspecific vocalizations at 9 months, it is not surprising that a relationship was not observed between speech preference and developmental outcomes at 12 months. These relations may only be observed during the window of time when younger SIBS-TD generally prefer conspecifics (Vouloumanos et al., 2010).

Differences in speech processing within the SIBS-A population may help to identify those individuals who will show later resilience in their developmental outcomes. Even if SIBS-A show atypical listening preferences for speech compared to SIBS-TD at a particular age, it does not mean that this will lead to atypical outcomes. In the current study, SIBS-A who showed the opposite preference (speech over monkey calls) compared with SIBS-TD at 9 months had larger vocabularies and demonstrated fewer indicators of autism-like behaviors at 12 months. This pattern is consistent with prior studies showing that atypically large ERP responses to repeated speech sounds in SIBS-A at 9 months had better later language abilities and were less likely to be diagnosed with ASD at 36 months (Seery et al., 2014). Thus, larger or delayed responses to speech may actually predict resilience in later development. While we do not have diagnostic outcomes for the SIBS-A in the current study, individuals who prefer speech at 9 months may be less likely to show later atypical social or language development. While we are cautious to not over-state the importance of the present findings, we suggest that a practical implication of these results is that increased attention to speech among this heterogeneous, at-risk population may be a marker of future resilience.

We interpret our results as suggesting that attention to speech early in development is related to later linguistic and social-communicative development for infants at elevated risk for ASD. While a possible mechanism for these differences is an early and initial failure of the brain to develop specialized social information and linguistic processing functions in ASD (Pelphrey, Shultz, Hudac, & Vander Wyk, 2011), speech-based interactions between infant and caregiver that promote a 'social feedback loop' may also be disrupted. That is, TD infants and young children who produce more social vocalizations tend to receive more social communicative responses from their caregivers, thus promoting language development over time (Warlaumont, Richards, Gilkerson, & Oller, 2014). However, children diagnosed with ASD tend to produce fewer speech-related vocalizations and the responses from their caregivers tend to be less contingent upon their vocalizations. These differences may weaken the social feedback loop and negatively impact later language development (Warlaumont, et al., 2014).

Preferences for speech early in infancy may play an important role in setting typical linguistic and social-communicative development, particularly for infant siblings of children with ASD, who are themselves at higher risk of later being diagnosed with ASD, language or other developmental delays, or showing subclinical features of ASD characteristic of the broader autism phenotype (Ozonoff et al., 2014). Our findings indicate that these preferences may coexist with infants' propensity to attend to new information at 9 months. However, for infants at risk of being diagnosed with ASD, continuing to attend to speech sounds may

serve as a protective factor for their later language and social development. Overall, our findings demonstrate the foundational importance of early speech processing for language and social development and may provide a starting point for identifying divergent patterning in populations at higher risk of developing atypical linguistic and social-communication skills.

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Research Highlights:

- Typical 9-month-olds prefer speech to non-speech but monkey calls to speech
- SIBS-A differ in listening preferences from SIBS-TD
- SIBS-A prefer speech to non-speech but don't prefer speech or monkey calls
- SIBS-A who listen more to speech have better language and social development
- Maintaining attention to speech may signal improved development for SIBS-A

Figure 1.

Results: Scatterplots of individual 9-month-old (black circles) SIBS-A and SIBS-TD relative looking times for speech compared to non-speech (Experiment 1; left) and speech compared to monkey calls (Experiment 2; right), with group means represented by horizontal bars. Positive values indicate a preference for speech and negative values indicate a preference for non-speech (Experiment 1; left) or monkey calls (Experiment 2; right).

Figure 2.

Scatterplot of Speech Preference Index at 9 months on MB-CDI Words Understood and Words Produced at 12 months for SIBS-A and SIBS-TD groups in Experiment 1.

Figure 3.

Scatterplot of Speech Preference Index at 9 months on AOSI Total Score and AOSI Total Markers at 12 months for SIBS-A and SIBS-TD groups in Experiment 1.

Figure 4.

Scatterplot of Speech Preference Index at 9 months on MB-CDI Words Understood and Words Produced at 12 months for SIBS-A and SIBS-TD groups in Experiment 2.

Figure 5. Scatterplot of Speech Preference Index at 9 months on AOSI Total Score and AOSI Total Markers at 12 months for SIBS-A and SIBS-TD groups in Experiment 2.

Table 1.

Participant information and descriptive statistics for experimental and observational tasks in Experiment 1 (speech vs. non-speech; top) and Experiment 2 (speech vs. monkey calls; bottom).

	Exp. 1: Speech vs. Non-Speech						
	SIBS-A				SIBS-TD		
Parental information	N	M	SD	Sig	N	M	SD
Maternal Education	38	7.1	1.5	p = .06	59	7.7	0.9
Household Income	37	6.7	2.4	ns	59	7.3	2.3
9 months							
Chronological age at testing	38	9.3	0.5	p = .05	60	9.1	0.6
Speech Preference Index	38	1.8	5.4	ns	60	1.4	5.2
Pre-test	38	17.1	10.6	ns	60	17.6	10.7
Post-test	38	15.7	11.0	ns	60	13.7	10.5
AOSI Total Score	39	6.7	4.1	ns	60	5.6	3.4
AOSI Total Markers	39	4.3	2.0	ns	60	3.7	2.0
12 months							
Chronological age at testing	37	12.4	0.4	p = .06	57	12.6	0.5
MB-CDI Words Understood	36	39.3	31.7	ns	52	31.3	25.5
MB-CDI Words Produced	36	49.3	19.4	p = .06	52	45.1	18.2
AOSI Total Score	37	6.0	4.6	p = .06	57	4.5	3.1
AOSI Total Markers	37	4.0	2.6	ns	57	3.1	1.9
MSEL Gross Motor T	38	43.7	11.7	ns	56	45.5	11.8
MSEL Gross Motor Age Equivalent	38	12.1	2.2	ns	56	12.5	2.0
MSEL Fine Motor T	38	56.2	10.9	ns	56	56.5	9.2
MSEL Fine Motor Age Equivalent	38	14.3	2.1	ns	56	14.6	1.9
MSEL Visual Reception T	38	49.8	8.0	ns	56	51.3	9.8
MSEL Visual Reception Age Equivalent	38	12.7	1.6	ns	56	13.2	2.2
MSEL Receptive Language T	36	38.4	6.6	ns	56	40.5	9.0
MSEL Receptive Language Age Equivalent	36	9.8	1.7	ns	56	10.4	2.1
MSEL Expressive Language T	38	51.8	9.7	ns	55	51.6	9.7
MSEL Expressive Language Age Equivalent	38	12.7	2.3	ns	55	12.9	2.2
MSEL Early Learning Composite	36	47.3	24.5	ns	55	49.9	26.3
	Exp. 2: Speech vs. Monkey Calls						
	SIBS-A				SIBS-TD		
Parental information	N	M	SD	Sig	N	M	SD
Maternal Education	46	7.1	1.4	p = .03	53	7.7	0.9
Household Income	44	7.1	2.5	ns	53	7.8	2.2
9 months							
Chronological age at testing	46	9.3	0.5	ns	54	9.2	0.5
Speech Preference Index	46	-0.8	7.0	ns	54	-2.0	6.6

Pre-test	46	22.4	11.4	ns	54	19.5	11.6
Post-test	46	15.9	11.2	ns	54	15.9	10.2
AOSI Total Score	46	6.7	4.0	p = .07	54	5.4	3.3
AOSI Total Markers	46	4.3	2.1	p = .08	54	3.6	1.9
12 months							
Chronological age at testing	44	12.4	0.3	p = .05	52	12.6	0.4
MB-CDI Words Understood	42	38.7	30.7	ns	47	37.9	27.9
MB-CDI Words Produced	42	49.2	19.5	ns	47	45.0	18.7
AOSI Total Score	44	5.9	4.4	ns	52	4.9	3.6
AOSI Total Markers	44	3.9	2.5	ns	52	3.2	2.2
MSEL Gross Motor T	45	43.5	11.0	ns	51	45.3	12.8
MSEL Gross Motor Age Equivalent	45	12.0	2.1	ns	51	12.5	2.2
MSEL Fine Motor T	45	55.6	10.1	ns	50	57.3	9.3
MSEL Fine Motor Age Equivalent	45	14.2	2.0	ns	50	14.6	1.8
MSEL Visual Reception T	45	49.9	7.5	ns	50	50.9	10.1
MSEL Visual Reception Age Equivalent	45	12.7	1.5	ns	50	13.1	2.2
MSEL Receptive Language T	43	39.4	8.6	ns	51	40.0	8.2
MSEL Receptive Language Age Equivalent	43	10.1	2.2	ns	51	10.4	2.1
MSEL Expressive Language T	45	52.6	10.6	ns	50	51.3	9.3
MSEL Expressive Language Age Equivalent	45	13.0	2.5	ns	50	12.9	2.3
MSEL Early Learning Composite	43	48.1	23.8	ns	49	49.5	26.0
Exps. 1 & 2: Sample Overlap							
SIBS-A				SIBS-TD			
Parental information	N	M	SD	Sig	N	M	SD
Maternal Education	37	7.1	1.5	p = .03	42	7.7	0.9
Household Income	35	6.8	2.5	ns	42	7.6	2.3
9 months							
Chronological age at testing	37	9.3	0.5	ns	43	9.2	0.5
AOSI Total Score	37	6.9	4.2	ns	43	5.6	3.4
AOSI Total Markers	37	4.4	2.1	ns	43	3.7	2.0
12 months							
Chronological age at testing	36	12.4	0.4	ns	41	12.5	0.3
MB-CDI Words Understood	34	38.2	31.6	ns	37	34.2	26.8
MB-CDI Words Produced	34	48.5	18.7	ns	37	44.0	19.5
AOSI Total Score	35	6.1	4.7	ns	41	4.7	3.3
AOSI Total Markers	35	4.0	2.7	ns	41	3.2	2.1
MSEL Gross Motor T	36	42.8	11.4	ns	40	44.3	12.0
MSEL Gross Motor Age Equivalent	36	11.9	2.2	ns	40	12.3	2.0
MSEL Fine Motor T	36	55.5	10.7	ns	40	56.1	9.2
MSEL Fine Motor Age Equivalent	36	14.2	2.0	ns	40	14.4	1.8

MSEL Visual Reception T	36	49.9	7.8	ns	40	51.2	10.5
MSEL Visual Reception Age Equivalent	36	12.7	1.6	ns	40	13.1	2.3
MSEL Receptive Language T	34	37.7	6.1	p = .08	40	40.8	8.4
MSEL Receptive Language Age Equivalent	34	9.6	1.6	p = .05	40	10.5	2.0
MSEL Expressive Language T	36	51.3	9.7	ns	39	52.4	9.7
MSEL Expressive Language Age Equivalent	36	12.6	2.3	ns	39	13.1	2.3
MSEL Early Learning Composite	34	45.1	23.4	ns	39	50.6	27.0

Note. AOSI = Autism Observation Scale for Infants; MD-CDI = MacArthur Bates Communicative Development Inventories; MSEL = Mullen Scales of Early Learning

Table 2.

Correlations among predictor variable, covariates, and language and social outcome variables in Experiment 1 (speech vs. non-speech; top) and Experiment 2 (speech vs. monkey calls; bottom).

	Exp. 1: Speech vs. Non-Speech						
	SIBS-A						
	1	2	3	4	5	6	7
1. Speech Preference Index	-						
2. MB-CDI Words Understood	.34 *	-					
3. MB-CDI Words Produced	.22	.59 ***	-				
4. AOSI Total Score 9 months	-.03	-.08	-.16	-			
5. AOSI Total Markers 9 months	-.03	.03	-.03	.91 ***	-		
6. AOSI Total Score 12 months	-.33 *	-.27	.02	.34 *	.36 *	-	
7. AOSI Total Markers 12 months	-.33 *	-.20	.08	.25	.32 *	.96 ***	-
	SIBS-TD						
	1	2	3	4	5	6	7
1. Speech Preference Index	-						
2. MB-CDI Words Understood	.00	-					
3. MB-CDI Words Produced	.02	.28 *	-				
4. AOSI Total Score 9 months	-.08	-.06	-.12	-			
5. AOSI Total Markers 9 months	-.03	-.10	-.17	.93 ***	-		
6. AOSI Total Score 12 months	-.07	-.08	-.08	.25 †	.25 †	-	
7. AOSI Total Markers 12 months	-.01	-.10	-.06	.22 †	.23 †	.93 ***	-
	Exp. 2: Speech vs. Monkey Calls						
	SIBS-A						
	1	2	3	4	5	6	7
1. Speech Preference Index	-						
2. MB-CDI Words Understood	.20	-					
3. MB-CDI Words Produced	.29 †	.56 ***	-				
4. AOSI Total Score 9 months	.04	-.14	-.14	-			
5. AOSI Total Markers 9 months	.05	.01	-.04	.85 ***	-		
6. AOSI Total Score 12 months	-.26 †	-.33 *	-.06	.35 *	.30 *	-	
7. AOSI Total Markers 12 months	-.29 †	-.30 †	-.06	.29 †	.29 *	.97 ***	-
	SIBS-TD						
	1	2	3	4	5	6	7
1. Speech Preference Index	-						
2. MB-CDI Words Understood	-.14	-					

3. MB-CDI Words Produced	.04	.23	-				
4. AOSI Total Score 9 months	-.14	-.24	-.19	-			
5. AOSI Total Markers 9 months	-.14	-.25 [†]	-.23	.94 ^{***}	-		
6. AOSI Total Score 12 months	.16	-.14	-.18	.18	.25 [†]	-	
7. AOSI Total Markers 12 months	.16	-.14	-.18	.15	.22	.95 ^{***}	-

Note. AOSI = Autism Observation Scale for Infants; MB-CDI = MacArthur Bates Communicative Development Inventories;

p < .001.

**
p < .01.

*
p < .05.

[†]
p < .10.

Table 3.

Predictive effects of speech preference, risk group, and the interaction of speech preference and risk group on language in Experiment 1 (speech vs. non-speech; top) and Experiment 2 (speech vs. monkey calls; bottom).

Exp.1 : Speech vs. Non-Speech								
Words Understood					Words Produced			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Step 1								
Constant	.03	34.61	2.99	[28.66, 40.56]	.01	46.82	1.99	[42.86, 50.78]
SPI		0.78	0.51	[-0.23, 1.79]		0.32	0.34	[-0.35, 0.99]
Step 2								
Constant	.02	31.14	3.87	[23.44, 38.84]	.01	45.00	2.59	[39.85, 50.14]
SPI		0.82	0.51	[-0.19, 1.82]		0.34	0.34	[-0.33, 1.01]
Risk Group		8.49	6.06	[-3.56, 20.54]		4.45	4.05	[-3.60, 12.51]
Step 3								
Constant	.03 [†]	31.33	3.84	[23.69, 38.96]	.01	45.07	2.59	[39.91, 50.22]
SPI		0.00	0.71	[-1.42, 1.42]		0.05	0.48	[-0.91, 1.01]
Risk Group		8.64	6.01	[-3.31, 20.59]		4.51	4.06	[-3.56, 12.58]
SPI * Risk Group Interaction	1.61	1.00	[-0.39, 3.60]		0.58	0.68	[-0.77, 1.92]	
Exp. 2: Speech vs. Monkey Calls								
Words Understood					Words Produced			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Step 1								
Constant	.00	38.24	3.10	[32.08, 44.39]	.02	46.96	2.01	[42.96, 50.95]
SPI		0.16	0.46	[-0.76, 1.08]		0.40	0.30	[-0.20, 1.00]
Step 2								
Constant	.00	38.02	4.32	[29.44, 46.60]	.00	45.36	2.79	[39.81, 50.90]
SPI		0.16	0.47	[-0.78, 1.10]		0.36	0.31	[-0.25, 0.96]
Risk Group		0.46	6.33	[-12.12, 13.04]	3.39	4.09	[-4.75, 11.52]	
Step 3								
Constant	.03	37.21	4.31	[28.65, 45.77]	.03	44.85	2.79	[39.31, 50.39]
SPI		-0.60	0.67	[-1.93, 0.72]		-0.12	0.43	[-0.98, 0.74]
Risk Group		0.40	6.27	[-12.07, 12.86]	3.34	4.06	[-4.72, 11.41]	
SPI * Risk Group Interaction	1.50	0.94	[-0.35, 3.36]		0.94	0.61	[-0.26, 2.14]	

p < .001.

^{**}
p < .01.

^{*}
p < .05.

[†]
p < .10.

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Table 4.

Predictive effects of speech preference, risk group, and the interaction of speech preference and risk group on social development in Experiment 1 (speech vs. non-speech; top) and Experiment 2 (speech vs. monkey calls; bottom).

	Exp. 1: Speech vs. Non-Speech							
	Total Score				Total Markers			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Step 1								
Constant	.04*	5.09	0.39	[4.33, 5.86]	.03[†]	3.46	0.23	[3.01, 3.91]
SPI		-0.14	0.07	[-0.27, 0.00]		-0.07	0.04	[-0.15, 0.01]
Step 2								
Constant	.04*	4.50	0.49	[3.53, 5.47]	.04*	3.11	0.29	[2.54, 3.68]
SPI		-0.13	0.07	[-0.27, 0.00]		-0.07	0.04	[-0.14, 0.01]
Risk Group		1.50	0.78	[-0.05, 3.04]		0.88	0.46	[-0.03, 1.78]
Constant	.02*	4.49	0.49	[3.53, 5.46]	.03*	3.11	0.28	[2.54, 3.67]
SPI		-0.04	0.09	[-0.22, 0.14]		0.00	0.05	[-0.11, 0.11]
Risk Group		1.49	0.77	[-0.05, 3.03]		0.87	0.45	[-0.03, 1.77]
SPI * Risk Group Interaction	-0.19	0.13	[-0.45, 0.07]		-0.13	0.08	90.28, 0.02]	
Exp. 2: Speech vs. Monkey Calls								
	Total Score				Total Markers			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Step 1								
Constant	.00	5.34	0.41	[4.52, 6.16]	.00	3.51	0.24	[3.03, 3.98]
SPI		-0.03	0.06	[-0.15, 0.09]		-0.02	0.04	[-0.09, 0.05]
Step 2								
Constant	.02	4.86	0.56	[3.74, 5.97]	.02	3.19	0.32	[2.55, 3.84]
SPI				[-0.16, 0.08]		-0.02	0.04	[-0.09, 0.05]
Risk Group		-0.04	0.06	[-0.60, 2.70]		0.68	0.48	[-0.27, 1.64]
Step 3								
Constant	.04	4.95	0.55	[3.85,	.05[†]	3.25	0.32	[2.62,
				6.05]				3.89]
SPI		0.09	0.08	[-0.08, 0.25]		0.05	0.05	[-0.04, 0.15]
Risk Group		1.02	0.82	[-0.60, 2.64]		0.66	0.47	[-0.27, 1.60]
SPI * Risk Group Interaction	-0.24	0.12	[-0.48, -0.01]		-0.16	0.07	[-0.29, -0.02]	

p < .001.

**
p < .01.

*
p < .05.

$\dagger$
 $p < .10$.

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Table 5.

Predictive effect of speech preference on language in Experiment 1 (speech vs. non-speech; top) and Experiment 2 (speech vs. monkey calls; bottom).

Exp. 1: Speech vs. Non-Speech - Words Understood								
	SIBS-A				SIBS-TD			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Constant	.11*	39.97	5.06	[29.69, 50.24]	.00	31.33	3.57	[24.15, 38.50]
SPI		1.61	.77	[-.04, 3.16]		.00	.66	[-1.33, 1.34]
Exp. 1: Speech vs. Non-Speech - Words Produced								
	SIBS-A				SIBS-TD			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Constant	.05	49.57	3.18	[43.01, 56.04]	.00	45.07	2.56	[39.93, 50.20]
SPI		.63	.49	[-.36, 1.61]		.05	.48	[-.91, 1.00]
Exp. 2: Speech vs. Monkey Calls - Words Understood								
	SIBS-A				SIBS-TD			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Constant	.04	37.61	4.76	[27.99, 47.22]	.02	37.21	4.13	[28.89, 45.53]
SPI		.90	.69	[-.49, 2.28]		-.61	.64	[-1.89, .68]
Exp. 2: Speech vs. Monkey Calls - Words Produced								
	SIBS-A				SIBS-TD			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Constant	.09 [†]	48.20	2.95	[42.23, 54.16]	.00	44.85	2.79	[39.24, 50.46]
SPI		.82 [†]	.43	[-.04, 1.68]		-.12	.43	[-.99, .75]

p < .001.

**
p < .01.

*
p < .05.

[†]
p < .10.

Table 6.

Predictive effect of speech preference on social development in Experiment 1 (speech vs. non-speech; top) and Experiment 2 (speech vs. monkey calls; bottom).

	Exp. 1: Speech vs. Non-Speech - AOSI Total Score							
	SIBS-A				SIBS-TD			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Step 1								
Constant	.12*	5.77	.73	[4.29, 7.24]	.06[†]	4.59	.41	[3.78, 5.40]
AOSI Total Score 9 months		.40	.19	[.02, .79]		.22	.12	[−.01, .46]
Step 2								
Constant	.08[†]	5.76	.70	[4.33, 7.19]	.00	4.59	.41	[3.77, 5.41]
AOSI Total Score 9 months		.36	.19	[−.02, .73]				
SPI		−.20	.11	[−.42, .02]				
	Exp. 1: Speech vs. Non-Speech - AOSI Total Markers							
	SIBS-A				SIBS-TD			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Step 1								
Constant	.10*	3.85	.42	[3.00, 4.69]	.05[†]	3.16	.25	[2.67, 3.65]
AOSI Total Markers 9 months		.43	.22	[−.01, .87]		.21	.12	[−.04, .46]
Step 2								
Constant	.09[†]	3.83	.40	[3.02, 4.65]	.00	3.16	.25	[2.66, 3.66]
AOSI Total Markers 9 months		.40	.21	[−.02, .83]		.21	.12	[−.04, .46]
SPI		−.12	.06	[−.25, .00]		−.00	.05	[−.10, .09]
	Exp. 2: Speech vs. Monkey Calls - AOSI Total Score							
	SIBS-A				SIBS-TD			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Step 1								
Constant	.12**	5.62	.64	[4.32, 6.91]	.03	5.00	.51	[3.98, 6.02]
AOSI Total Score 9 months		.41*	.17	[.07, .75]		.19	.15	[−1.07, .50]
Step 2								
Constant	.08[†]	5.70	.62	[4.44, 6.96]	.03	5.10	.51	[4.07, 6.12]
AOSI Total Score 9 months		.43*	.16	[.10, .76]		.23	.15	[−.08, .53]
SPI		.17 [†]	.09	[−.35, .00]		.10	.08	[−.05, .26]

	Exp. 2: Speech vs. Monkey Calls - AOSI Total Markers							
	SIBS-A				SIBS-TD			
	R2	B	SE	95 % CI	R2	B	SE	95 % CI
Step 1								
Constant	.09*	3.72	.37	[3.00, 4.47]	.05	3.30	.30	[2.70 , 3.89]
AOSI Total Markers 9 months		.37	.19	[−.01, .75]		.25	.15	[−.05, .56]
Step 2								
Constant	.10*	3.77	.36	[3.05, 4.49]	.04	3.36	.30	[2.76, 3.96]
AOSI Total Markers 9 months		.40	.18	[.04, .76]		.28	.15	[−.03, .59]
SPI		−.11	.05	[−.21, −.01]		.07	.05	[−.03, .16]

p < .001.

**
p < .01.

*
p < .05.

†
p < .10.