Foundational Tuning: How Infants’ Attention to Speech Predicts Language Development

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Abstract

Orienting biases for speech may provide a foundation for language development. Although human infants show a bias for listening to speech from birth, the relation of a speech bias to later language development has not been established. Here, we examine whether infants’ attention to speech directly predicts expressive vocabulary. Infants listened to speech or non-speech in a preferential listening procedure. Results show that infants’ attention to speech at 12 months significantly predicted expressive vocabulary at 18 months, while indices of general development did not. No predictive relationships were found for infants’ attention to non-speech, or overall attention to sounds, suggesting that the relationship between speech and expressive vocabulary was not a function of infants’ general attentiveness. Potentially ancient evolutionary perceptual capacities such as biases for conspecific vocalizations may provide a foundation for proficiency in formal systems such as language, much like the approximate number sense may provide a foundation for formal mathematics.

Keywords: Cognitive development; Language acquisition; Speech perception; Longitudinal; Predictor

1. Introduction

To learn language, children must be able to select meaningful signals among the range of stimuli in their environment. This requires infants learning a spoken language to distinguish and attend to speech—linguistic sounds generally produced by the human vocal tract. Many species show a bias for their own species’ (i.e., conspecific) vocalizations over other species’ vocalizations. For example, swamp sparrows preferentially learn conspecific song compared with heterospecific sparrow song (e.g., Marler & Peters, 1977).
Human infants have similar biases for the communicative signals of their species, privileging speech over filtered speech (Spence & DeCasper, 1987), warbled tones (Samples & Franklin, 1978), white noise (Butterfield & Siperstein, 1970; Colombo & Bundy, 1981), and synthetic sine-wave analogs of speech (Vouloumanos & Werker, 2004, 2007). Recently, Shultz and Vouloumanos (2010) found that 3-month-old infants preferred listening to speech compared with other naturally occurring sounds in their environment, even other human communicative sounds such as laughter. A bias for speech, apparent even in newborns (Vouloumanos & Werker, 2007), may constitute an orienting mechanism toward conspecific linguistic vocalizations that provides a foundation for subsequent language development. In this paper, we examine whether an attentional bias for speech predicts later language development. Extracting species-specific linguistic signals from their auditory environments could allow infants to analyze speech signals more thoroughly, providing a mechanism for early language acquisition.

Language development is influenced by competence in underlying sensory systems; specifically, spoken language perception relies on basic auditory processing. For example, infants’ rapid auditory processing abilities at 7.5 months predict emerging language abilities at 24 months (Benasich & Tallal, 2002). Findings with children yield similar results; identification of speech sounds in noise predicts language impairment in children with Specific Language Impairment, and in typically developing participants (Ziegler, Pech-Georgel, George, Alario, & Lorenzi, 2005). Language development is thus affected by competence in the basic sensory systems that support its functions: Individuals with better auditory skills achieve better spoken language proficiency.

More specifically, early speech perception abilities predict some aspects of later language skills. For example, infants’ discrimination of two acoustically distinct vowels (/u/ and /y/) at 6 months significantly correlates with language abilities at 13–24 months of age (Tsao, Liu, & Kuhl, 2004). Similarly, performance on a word–object associative learning task using minimally differing words, such as bih and dih (Stager & Werker, 1997) at 17 and 20 months is related to performance on children’s standardized tests of language comprehension and production up to two and a half years later (Bernhardt, Kemp, & Werker, 2007). This suggests that infants’ ability to associate minimally distinct words to objects, which requires sensitivity to phonological differences, might be related to later word learning abilities. Other speech processing abilities such as speech segmentation at 12 months also correlate with expressive vocabulary at 24 months and language skills at 4–6 years, though not with IQ (Newman, Ratner, Jusczyk, Jusczyk, & Dow, 2006). At the same time, studies of infants’ lexical processing show that speed and accuracy in word recognition at 25 months are correlated with earlier lexical and grammatical development from 12 to 25 months and with expressive language, IQ and working memory at 8 years; but speed of word recognition at 15 and 18 months does not predict measures of lexical and grammatical development at 25 months, leaving open the specific relationships between the constructs (Fernald, Perfors, & Marchman, 2006; Marchman & Fernald, 2008). However, as these authors acknowledge, the relationship between speech perception abilities and
language development could be due to non-linguistic factors such as general cognitive and/or social skills, rather than being specific to language learning.

Indeed, general cognitive factors influence speech perception abilities in infancy. For example, infants between 8 and 11 months who succeeded on A-not-B and means-end tasks showed reduced discrimination of non-native speech contrasts, while their native speech discrimination remained intact (Conboy, Sommerville, & Kuhl, 2008; Lalonde & Werker, 1995). The negative relationship between discrimination of non-native speech contrasts and cognitive control may result from infants’ developing ability to attend to relevant rather than irrelevant information (e.g., Werker & Curtin, 2005). Both the cognitive tasks and the speech perception tasks required infants to inhibit attention to irrelevant information and tapped into the same underlying ability: inhibitory control (Conboy et al., 2008; Lalonde & Werker, 1995). Moreover, one of these studies suggested a specific relationship between 11-month-old infants’ attention to relevant information (reflected in better discrimination of native speech contrasts) and their vocabulary size assessed at the same age (Conboy et al., 2008). These studies did not, however, examine whether attention to relevant information at an earlier age may predict aspects of language development such as expressive vocabulary at a later age.

Preliminary evidence that individual infants’ attention to speech sounds more generally could have an impact on their language development comes from studies of atypical language development. Kuhl, Coffey-Corina, Padden, and Dawson (2005) tested auditory preferences for infant-directed speech samples pitted against non-speech analogs in 2.5–4-year-old children with autism spectrum disorder (ASD). They found that the children with ASD who preferred listening to non-speech over speech were more likely to exhibit deficits in expressive language ability, suggesting that attention to speech is related to language production within individual children. Further, children with language impairments also show atypical preferences for particular types of speech stimuli relative to typically developing children. Five-year olds with autism do not orient reliably to their name (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998) and 3–4-year-olds with autism prefer listening to superimposed voices over their mother’s voice (Klin, 1992). This contrasts with typically developing children, who attend to their name by 4.5 months of age (Mandel, Jusczyk, & Pisoni, 1995) and prefer listening to their mother’s voice from birth (DeCasper & Fifer, 1980). Early processing differences for speech may also predict reading ability in school-age children, as neonatal electrophysiological responses to speech and non-speech predicted children who were dyslexic or below average readers at 8 years of age (Molfese, 2000). Together, this work suggests that the absence of typical responses to speech may be associated with delays or impairments in language development. However, the relation between a speech bias and language development in the general population, and in particular the degree to which attention to speech predicts later expressive vocabulary development, has not been examined. Nor is it known whether early speech processing is related specifically to later language abilities or whether it reflects more general cognitive abilities.

In this study, we examine a cohort of infants prospectively and test whether attention to speech at 12 months predicts expressive vocabulary at 18 months. We also examine
the degree to which infants’ general cognitive and motor development correlates with attention to speech and language outcomes at 18 months. At the same time, we consider two alternative possibilities: that language development is related to increased general attentiveness to sounds, or to more advanced general development, two possibilities which would ground language development in earlier general cognitive competencies (e.g., Lalonde & Werker, 1995) rather than more specific attention to speech.

2. Method

2.1. Participants

Thirty infants (\(M_{\text{age}} = 12.5\) months, \(SD = 0.26\)) participated in this study. Of these 30 infants, 27 completed the experimental task. We collected observational data (see below) from 29 infants at 12 months and 26 at 18 months, and parental reports of language development (see below) from 26 infants at 12 months and from 23 at 18 months.

2.2. Stimuli

Auditory stimuli were of two types (used in Vouloumanos & Werker, 2004, 2007): a speech set composed of 12 monosyllabic nonsense tokens of “lif” and “neem” spoken by a female native English speaker, and a non-speech set composed of 12 complex non-speech analogs matched to the 12 speech tokens. Each complex non-speech token consisted of four time-varying sinusoidal waves that track the center of the fundamental frequency (preserving pitch contour) and portions of the first three formants (F1, F2, and F3) of its speech counterpart while retaining the amplitude envelope, relative formant amplitude, and relative intensity of speech (Remez, Rubin, Berns, Pardo, & Lang, 1994; Remez, Rubin, Pisoni, & Carrell, 1981). Specifically, for the “lif” non-speech analogs, sine waves tracked the first formant of the initial consonant segment (“l”), and the first three formants of the vocalic segment (“i”). The analog for the fricative “f” was created using a filtered white noise generator. For the “neem” non-speech analogs, sine waves tracked the first formant of the initial (“n”) and final (“m”) consonants, and the first three formants of the vocalic segment (“ee”). Adults did not spontaneously perceive the non-speech analogs as speech (Vouloumanos, Kiehl, Werker, & Liddle, 2001). Each set of 12 tokens varied in intonational contour (average minimum and maximum pitch: 197 and 350 Hz, respectively) and duration (525–1,155 ms). Experimental trials consisted of tokens separated by 300–500 ms of silence presented at 65 ± 5 dB.

2.3. Experimental procedure

Infants were tested using a modified version of the sequential looking preference procedure (Cooper & Aslin, 1990, 1994; Vouloumanos & Werker, 2004). Infants were seated on a parent’s lap in front of a single video monitor. A movie of a flashing light was used
to attract the infant’s attention to the screen. Once the infant fixated on the screen, the trial was initiated. A black-and-white checkerboard was displayed in tandem with one set of sounds. Five speech trials and five non-speech trials were presented in random order. Stimulus presentation was of a fixed length: A trial consisted of tokens separated by 300–450 ms of silence, for a fixed trial length of 40 s. The presentation of auditory and visual stimuli was controlled by Habit X (Cohen, Atkinson, & Chaput, 2004). Infants were videotaped during the task to allow for offline coding. The main dependent measure was looking time to the checkerboard for each sound type.

2.4. Measures of linguistic development and general development

We assessed language development using the MacArthur-Bates Communicative Development Inventory (MB-CDI; Feldman et al., 2000; Fenson et al., 1994). The MB-CDI is a widely used parental report measure that has been validated in both typically developing and in atypical populations. Parents report children’s word comprehension and production. We converted the raw MB-CDI scores to percentiles (using published age-appropriate norms; Fenson et al., 2007) and used these in all analyses to test the relationship between attention to speech and expressive vocabulary.

Infants’ general development was assessed using the Mullen Scales of Early Learning (Mullen, 1995), a laboratory-based observational measure. The Mullen is a comprehensive assessment of language, motor, and perceptual abilities for children of all ability levels. The Mullen consists of five scales: visual reception (e.g., turns cup right-side up), receptive language (e.g., recognizes own name), expressive language (e.g., produces three consonant sounds), fine motor (e.g., uses pincer grasp while seated), and gross motor abilities (e.g., pulls self to stand). The Mullen Early Learning Composite score is designed to measure cognitive ability and is based on the first four scales. This is standardized for children aged 0–69 months. The gross motor scale covers children from 0 to 29 months.

3. Results

3.1. Overall preference for speech

At 12 months, infants listened to speech ($M = 12.0$ s, $SD = 5.2$) significantly longer overall than to non-speech ($M = 9.6$ s, $SD = 3.9$), $t(26) = 2.29$, $p = .03$, $r = .41$. A 2 (sound: speech, non-speech) by 5 (experimental block: 1, 2, 3, 4, 5) repeated-measures analysis of variance (ANOVA) revealed a main effect of sound, $F(1, 20) = 6.02$, $p = .023$, $\eta_p^2 = .23$, confirming longer listening to speech than non-speech, and a main effect of block, $F(4, 80) = 16.81$, $p < .001$, $\eta_p^2 = .46$, consistent with infants’ looking time decreasing over time. There was no reliable sound by block interaction, $F(4, 80) = 1.77$, $p = .14$, $\eta_p^2 = .08$, suggesting that the difference between speech and non-speech listening times was stable across blocks. Twenty of 27 infants listened longer to speech than non-speech (significant by binomial test, $p = .02$). This establishes that the speech prefer-
ence observed in prior studies in younger infants, from newborns to 7-month-olds (Vouloumanos & Werker, 2004, 2007), persists until the end of the first year of life.

3.2. Variability and reliability of parental report and observational measures

MB-CDI scores varied considerably between individuals. MB-CDI expressive language scores at 12 months ranged from 0 to 22 spoken words, with a mean of 7.8 words (SD = 7.3), similar to data reported in prior studies (Fenson et al., 1994). These correspond to MB-CDI expressive language percentile scores ranging from 1 to 87. MB-CDI expressive language scores at 18 months ranged from 0 to 320 spoken words, with a mean of 77.4 words (SD = 73.0). These correspond to MB-CDI expressive language percentile scores ranging from 1 to 97. Mullen Composite scores at 12 months varied between 84 and 126 (M = 103.7, SD = 9.6), and at 18 months varied between 66 and 127 (M = 100.7, SD = 15.9). MB-CDI expressive language percentile scores and Mullen Composite scores of general development were relatively stable across the two ages (MB-CDI: r = .57, N = 20, p = .009; Mullen: r = .34, N = 25, p = .093), although language measures seemed more stable than general development scores across this time period. Finally, parental reports of expressive vocabulary on the MB-CDI correlated with observational laboratory measures of expressive language using the Mullen at both ages (12 months: r = .76, N = 26, p < .001; 18 months: r = .77, N = 22, p < .001).

3.3. Specific relationship between orienting to speech and language development

We found a specific predictive relationship between orienting to speech and expressive language. We used multiple regression to test models with the following predictors of MB-CDI scores at 18 months: (Step 1) orienting time to speech at 12 months; (Step 2) Mullen Composite scores at 12 months; and (Step 3) MB-CDI scores at 12 months. Orienting time to speech at 12 months was the only significant predictor of MB-CDI scores at 18 months (see Table 1). When MB-CDI scores at 12 months were included as a predictor in the full model in Step 3, the effect size for orienting time to speech was modestly attenuated. In addition, the significance level dropped to marginal (p < .10), which might suggest that MB-CDI at 12 months was driving the effect. However, this seems unlikely as MB-CDI at 12 months was itself not a significant contributor and its effect size was much smaller. Orienting time to speech was consistently the largest relative predictor for MB-CDI scores at 18 months, and the only one that emerged significant at any step. When we included orienting time to non-speech and overall looking time as covariates in the model, the pattern of results remained the same with speech the only significant predictor of MB-CDI at 18 months (these results are not presented). Neither orienting time to non-speech nor overall looking time was a significant predictor.

We found no relationship between orienting to speech and general development at 18 months as measured by the Mullen Composite score. To test this relationship, we regressed the same predictors [(Step 1) orienting time to speech at 12 months; (Step 2) Mullen Composite scores at 12 months; and (Step 3) MB-CDI scores at 12 months] on
Mullen Composite scores at 18 months. The only significant predictor of Mullen Composite scores at 18 months was the Mullen Composite score at 12 months. Orienting time to speech was not a significant predictor (see Table 2). When we included orienting time to non-speech and overall looking time as covariates in the model results were similar, and neither orienting time to non-speech nor overall looking time was a significant predictor of Mullen Composite score at 18 months.

Table 1
Linear fixed effects model of predictor variables at 12 months on MB-CDI expressive language outcome at 18 months

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<thead>
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<th>Step</th>
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<tbody>
<tr>
<td></td>
<td>B</td>
<td>SE B</td>
<td>β</td>
</tr>
<tr>
<td>Step 1</td>
<td>Constant</td>
<td>−10.28</td>
<td>16.59</td>
</tr>
<tr>
<td></td>
<td>Orientation to speech</td>
<td>3.75</td>
<td>1.28</td>
</tr>
<tr>
<td>Step 2</td>
<td>Constant</td>
<td>−111.26</td>
<td>64.38</td>
</tr>
<tr>
<td></td>
<td>Orientation to speech</td>
<td>3.25</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>Mullen composite</td>
<td>1.04</td>
<td>.64</td>
</tr>
<tr>
<td>Step 3</td>
<td>Constant</td>
<td>−97.26</td>
<td>64.53</td>
</tr>
<tr>
<td></td>
<td>Orientation to speech</td>
<td>2.56</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td>Mullen composite</td>
<td>.81</td>
<td>.66</td>
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<tr>
<td></td>
<td>MB-CDI</td>
<td>.35</td>
<td>.29</td>
</tr>
</tbody>
</table>

Notes. $R^2 = .35$ for Step 1, $\Delta R^2 = .10$ for Step 2, $\Delta R^2 = .05$ for Step 3.

*p < .05. †p < .10.

Mullen Composite scores at 18 months. The only significant predictor of Mullen Composite scores at 18 months was the Mullen Composite score at 12 months. Orienting time to speech was not a significant predictor (see Table 2). When we included orienting time to non-speech and overall looking time as covariates in the model results were similar, and neither orienting time to non-speech nor overall looking time was a significant predictor of Mullen Composite score at 18 months.

Table 2
Linear fixed effects model of predictor variables at 12 months on Mullen general development scores at 18 months

<table>
<thead>
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<th>Step</th>
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<tbody>
<tr>
<td></td>
<td>B</td>
<td>SE B</td>
<td>β</td>
</tr>
<tr>
<td>Step 1</td>
<td>Constant</td>
<td>85.23</td>
<td>10.50</td>
</tr>
<tr>
<td></td>
<td>Orientation to speech</td>
<td>1.34</td>
<td>.84</td>
</tr>
<tr>
<td>Step 2</td>
<td>Constant</td>
<td>7.43</td>
<td>44.62</td>
</tr>
<tr>
<td></td>
<td>Orientation to speech</td>
<td>.87</td>
<td>.83</td>
</tr>
<tr>
<td></td>
<td>Mullen composite</td>
<td>.82</td>
<td>.46</td>
</tr>
<tr>
<td>Step 3</td>
<td>Constant</td>
<td>−14.13</td>
<td>45.24</td>
</tr>
<tr>
<td></td>
<td>Orientation to speech</td>
<td>1.41</td>
<td>.88</td>
</tr>
<tr>
<td></td>
<td>Mullen composite</td>
<td>1.13</td>
<td>.49</td>
</tr>
<tr>
<td></td>
<td>MB-CDI</td>
<td>−.32</td>
<td>.21</td>
</tr>
</tbody>
</table>

Notes. $R^2 = .12$ for Step 1, $\Delta R^2 = .14$ for Step 2, $\Delta R^2 = .09$ for Step 3.

*p < .05. †p < .10.
4. Discussion

Attention to speech predicts later language development. Infants who listened longer to speech at 12 months scored higher on expressive vocabulary measures at 18 months than infants with shorter listening times to speech. Notably, expressive vocabulary was not reliably predicted by overall looking time, looking time to non-speech, or general indices of development, speaking against the possibility that proficiency in expressive vocabulary was due to infants being generally more attentive or being more advanced in their general development. Instead, this finding is consistent with the proposal that an orienting mechanism toward conspecific linguistic vocalizations provides a foundation for subsequent language development.

Prior studies had shown a general predictive relationship between general auditory processing and language abilities (e.g., Benasich & Tallal, 2002). General relationships also exist between visual attention (habituation curves and subsequent recovery) in early infancy and higher standard intelligence scores in childhood (e.g., Bornstein & Sigman, 1986; Colombo, 2001; Lewis & Brooks-Gunn, 1981; Slater, 1997). Here, we show a specific relationship between increased attention to a particular type of auditory stimulus, speech, and later expressive vocabulary. These relatively specific effects are consistent with other domain-specific individual differences, for example, within the domain of number. Individual differences in the approximate number sense of 14-year-olds correlate with their past scores of mathematical achievement at the age of 6 (Halberda, Mazzocco, & Feigenson, 2008). This is consistent with specific relationships between potentially ancient evolutionary abilities—such as conspecific vocalization biases, and the approximate number sense—and proficiency in formal systems such as language and mathematics.

The current results complement and extend existing findings showing that specific speech perception abilities (e.g., vowel discrimination, speech segmentation, use of phonetic detail in word learning) are related to language abilities (e.g., Bernhardt et al., 2007; Newman et al., 2006; Tsao et al., 2004). Prior studies showed that specific phonetic abilities (e.g., discriminating between vowels) correlated with aspects of language performance (e.g., vocabulary size; Tsao et al., 2004), demonstrating that different language processing tasks that tap into a common underlying linguistic ability are related across development. This is consistent with findings suggesting that 17- to 20-month-olds’ ability to associate minimally distinct words to objects, which requires sensitivity to phonological differences, might influence later word learning abilities (Bernhardt et al., 2007). Here, we find evidence for a more general relationship between infants’ attention to a class of relevant stimuli and their expressive language abilities. Our analyses show that this relationship holds even when we include aspects of general development as measured by the Mullen scales as a predictor. It is possible that the lack of correlation between attention to speech and general development stems from lower variability in the general development scores. However, the proposed specificity of the relationship between attention to speech and later language is consistent with previous work showing that speech processing at 12 months correlates with expressive vocabulary at 24 months and language skills at 4–6 years of age but not with cognitive skills (Newman et al., 2006).
previous study suggests that speech processing does not predict later cognitive skills. Our results suggest the converse may also be true: Earlier measures of general development may not be strong predictors of later expressive language. Together these studies show that language skills and general development have separable components.

Although orienting time to speech was the only significant predictor of expressive vocabulary at 18 months, the effect only trended toward significance when we included expressive vocabulary at 12 months as a predictor, because vocabulary measures were highly correlated across ages. This final model is tightly controlled because by including 12-month expressive vocabulary as a predictor any remaining effect of orienting to speech is an effect over and above any variable that influenced expressive vocabulary at 12 months. Thus, although the orienting to speech effect is no longer significant at \( p < .05 \), the fact that it remains a large effect (\( \beta = .40 \)) is very promising. It will be important to replicate this effect in future research with a larger sample.

One open question concerns which properties of the speech stimulus draw infants’ attention. Speech is a complex, biological, and familiar sound for infants. Any one of these properties might suffice to draw infants’ attention, conferring an advantage in later language development. However, infants are selective in their listening preferences from an early age, with 3-month-olds attending to speech more than to other complex, biological, and familiar sounds such as human communicative vocalizations including laughter (as well as monkey vocalizations or environmental sounds that share some subsets of these properties; Shultz & Vouloumanos, 2010; Vouloumanos, Hauser, Werker, & Martin, 2010).

A second important unanswered question concerns the specific role that a bias for speech plays in language acquisition. A speech bias may facilitate language development; alternatively, a speech bias may be essential for language acquisition. Research with atypical populations may provide some insight into a possible facilitatory or foundational role for a speech bias (Marcus & Rabagliati, 2006). Individuals with ASD who experience language difficulties do not pay selective attention to speech sounds (Kuhl et al., 2005; Paul, Chawarska, Fowler, Cicchetti, & Volkmar, 2007). In addition to displaying general language delays (Baron-Cohen, 1995), word learning also appears to be different in ASD individuals. Although children diagnosed with ASD apply exclusion constraints like mutual exclusivity (de Marchena, Eigsti, Worek, Ono, & Snedeker, 2011), they do not take advantage of eye gaze as a cue for disambiguating which object is being labeled, and “weigh associative cues” more heavily (Baron-Cohen, Baldwin, & Crowson, 1997). The absence of a behavioral bias for speech in individuals with ASD is correlated with delays or impairments in language development (e.g., Kuhl et al., 2005), providing at least some evidence for a fundamental role for speech biases in language development.

A predictive relationship between attending to speech at 12 months and vocabulary at 18 months does not entail a causal relationship. Speech and later vocabulary may be linked through a range of possible relations. For example, infants who have learned that speech is relevant may listen longer to speech and produce more words at 12 months, and these infants then maintain their relatively high vocabulary 6 months later. Note that under this hypothesis, orienting to speech would cease to be a significant predictor of
expressive language at 18 months when expressive language at 12 months is a predictor in the model; our finding that the predictive effect remains strong though not significant leaves this possibility open, though we find it unlikely. At the same time, infants encounter speech in social communication contexts. Thus, another possibility is that infants’ ability to use the social context in which speech occurs influences later language development. Future work needs to clarify the nature of the relationship between listening to speech and later language development.

The demonstrated relationship between attending to speech and expressive language abilities has important implications for our understanding of mechanisms of language development and for assessing long-term language and social-communicative outcomes (Curtin & Vouloumanos, 2013). Deviations in speech preference may be early indicators of language delays and subsequent disorders.

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