Formant Frequencies of Vowels Produced by Infants with and without Early Onset Otitis Media

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Abstract

Samples of speech/babble were recorded from 18 infants on a longitudinal basis once every 3 months between 6 and 18 months of age. Nine of the infants were treated for at least one episode of otitis media at or before 6 months of age (Early Onset group) while the remaining infants experienced no ear infections during the first 6 months of life (Late Onset group). Analysis of the F1 and F2 frequencies of vowels contained within canonical syllables revealed no age or group related differences in the mean F1 or F2 frequencies, in the standard deviation of the F1 frequencies, or in the geometric mean of the F2/F1 ratio. However, the standard deviation of the F2 frequencies increased significantly with age. At 18 months of age, the standard deviation of the F2 frequencies was significantly smaller for the Early Onset group in comparison with the Late Onset group. These findings show that recurring otitis media with early onset can result in a restricted vowel space, mirroring previously reported findings for infants with more severe, sensori-neural hearing impairment.

Des échantillons de parole/babillage provenant de 18 enfants ont été enregistrés à des intervalles de 3 mois entre les ages de 6 et 18 mois. Neuf de ces enfants on été soignés pour au moins une épisode d'otite moyenne avant ou à l'age de 6 mois (Groupe aux attaques précoce), tandis que les autres enfants n'avait pas été atteints durant les 6 premiers mois de leur vie (Groupe aux attaques tardive). L'analyse des fréquences F1 et F2 des voyelles contenues dans les syllabes canoniques n'a pas révélé de différénce pour les ages ou entre les 2 groupes et ceci pour les moyennes respectives de F1 et de F2, ainsi que dans l'écart type de F1 et dans la moyenne géométrique du rapport F1\F2. Par contre, l'écart type de F1 et dans la moyenne fréquence F2 a augment significantivement avec l'age. L'écart type plus petit pour le groupe aux attaques précoces que pour le groupe aux attaques tardives. Ces résultats démontrent que les enfants qui développement de voyelles plus restreints. Ceci reflète des résultats préalable obtenues chez des enfants souffrants de perte neurosensorielle.

1. INTRODUCTION

1.1 Normal Development of Vowel Production

Stark (1980) traces the roots of vowel production to infant cry, remarking:"the newborn infant has two separate sound-making systems: one associated with expression of distress in which vocalic elements predominate and which has rhythmic and stress variation and pitch contours (p. 84)." Cry does share some features of vowel-like vocalizations in that it involves a relatively open vocal tract. However, the duration of the vocalic elements found in cry are considerably longer than would be found in adult-produced vowels.

Oller (1980) notes that fully resonant vocalic elements do not occur during the first few months of life in noncry vocalizations. Rather, quasiresonant vowels (QRVs) predominate during this period. These QRVs are produced with normal phonation but with the mouth closed or nearly closed, resulting in a syllabic nasal or nasalized vowel. Acoustically, QRNs are characterized by a broad band of low frequency resonances. The emergence of fully resonanant vowels (FRVs) with strong resonances above 1200 Hz is a primary characteristic of the expansion stage of vocal development, and occurs at approximately 4 months of age.

Buhr (1980) combined acoustic analysis with phonetic description of the vowels produced by a single infant during the period 16 through 64 weeks of age. He observed a remarkable consistency in vowel preferences throughout this period. For example, /ɛ/ was the most frequently occuring vowel during 22 of the 28 recording sessions. Buhr (1980), Kent and Bauer (1985), Davis and MacNeilage (1990), and Roug, Landberg, and Lundberg (1989) all found a preference for central or front low vowels, as opposed to back and high vowels. Kent and Murray (1982) measured the frequencies of the first three formants of vowels produced by infants aged 3, 6, and 9 months. The center point of the infants' vowel space remained at approximately 1 kHz, 3 kHz, and 5 kHz for F1, F2, and F3 respectively, regardless of age.

Despite a great deal of consistency in infant vowel productions, predictable developmental changes do occur. Specifically, the F1-F2 vowel space expands with age and there is a reduction in overlap among the vowel spaces associated with different vowels (Buhr, 1980; Kent & Murray, 1982). In addition, there is an age-related reduction in the frequency of vocalizations produced with abnormal phonation (i.e., harmonic doubling, biphonation, F0 shift, vibrato, vocal tremor, and nasalization; Kent & Murray, 1982; Robb & Saxman, 1988).

Developmental changes in vowel production are typically attributed to maturation of oral-motor structure and function. Anatomical differences between the infant and adult vocal tracts, and neurophysiological immaturity with respect to motor development make it difficult for the newborn to produce speech-like sounds. The emergence of FRVs is attributed to functionally-driven anatomical changes that occur at approximately four months of age: maturation of the intrinsic muscles of the tongue and a reshaping of the oral cavity allows for greater tongue mobility; disengagement of the larynx from the nasopharynx allow for greater separation of the oral and nasal cavities; the larynx descends, enhancing the impact of the supralaryngeal muscles on laryngeal function. Neurophysiological developments that occur at approximately 6 to 7 months of age are said to account for the greater stability in the phonatory characteristics of vowels as well as the reduction in overlap of the acoustic vowel spaces associated with different vowels. Neurophysiological maturation also underlies the onset of canonical babbling during this period (Kent, 1992; Kent & Murray, 1982; Thelen, 1991). Canonical babble (CB) consists of single consonant-vowel (CV) syllables and strings of reduplicated syllables that are characterized by normal phonation and relatively mature timing characteristics (Oller, 1986).

1.2 The Role of the Auditory Environment

Although maturation of the articulatory system is undeniably important, it has also become clear that the auditory environment plays a critical role in early vocal development. For example, there is now evidence for "babbling drift", with the observation of crosslinguistic variation in vowel formants produced by 10 month old infants growing up in English, French, Arabic and Cantonese speaking environments (de Boysson-Bardies, Halle, Sagart, & Durand, 1989).

Kent, Osberger, Netsell, and Hustedde (1987) studied the speech produced by twin boys, one with normal hearing and one with profoundly impaired hearing, during the period 8 through 15 months of age. Acoustic analysis revealed that the hearing impaired baby's F1-F2 vowel space became increasingly restricted with age, while the vowel space of the normal hearing baby changed shape to resemble that of the adult speaker of English. (A larger literature exists regarding the effect of profound hearing impairment on the syllabic and consonantal characteristics of infant speech, but will not be reviewed here; e.g., Eilers & Oller, 1994; Kent, et al., 1987; Oller & Eilers, 1988; Stoel-Gammon & Otomo, 1986).

Two recent case studies suggest that the milder conductive hearing impairment associated with otitis media (OM) might also impact on early phonetic development. Donahue (1993) reported a diary study of a child who demonstrated delays in both phonological and expressive language skills, secondary to chronic otitis media during the first year of life. Although this child produced her first words at the early age of 9 months, her word productions for the next 7 months were based on the prosodic, rather than the segmental, features of words (specifically, her expressive words tended to have unique prosodic patterns but variable segmental characteristics). Consequently, her expressive vocabulary size was limited until the age of 17 months, when she abandoned the "tone language" strategy and subsequently increased her expressive vocabulary from 20 to 120 words within a two month period.

Robb, Psak and Pang-Ching (1993) documented phonetic inventories for a boy who underwent bilateral tympanoplasty tube insertion before 11 months of age for treatment of chronic OM. Assessments conducted at monthly intervals revealed that his phonetic repertoire was age-appropriate at 11 months in comparison with published norms. Over time his phonetic repertoire became increasingly restricted so that by 14 months of age only [m] and [h] were observed. The number of different consonants used gradually returned to normal during the next 5 months. They also reported that his consonant to vowel ratio was consistently lower than expected throughout the course of the study.

1.3 Purpose of the Study

The purpose of the present study was to examine the effect of OM on vowel production by children between 6 and 18 months of age. This study adds to the literature described previously by using a larger sample of children and systematic assessment techniques applied at regular intervals in a longitudinal design.

2. METHOD

2.1 Subjects

Eighteen infants were referred by community health nurses or family physicians at or before the age of 6 months. Nine of the infants were reported to have had no known ear infections before referral (although many of them experienced ear infections at a later age), while the remaining infants had received antibiotic treatment for at least one ear infection at or before the age of 6 months. These two groups of children will be referred to as the "Late Onset (LO)" and "Early Onset (EO)" groups respectively.

The Late Onset group consisted of 5 boys and 4 girls while the Early Onset group consisted of 6 boys and 3 girls. All of the infants had unremarkable birth, developmental, and family histories at time of referral. All of the infants lived in two-parent homes with at least one employed parent. All parents were native speakers of English. The mean number of years of education for the mothers was 15.11 and 13.77 for the Late and Early Onset groups respectively. The mean number of years of education for the fathers was 14.9 and 14.0 for the Late and Early Onset groups respectively. The range across groups was 12 to 16 years of education for the mothers and 10 to 20 years of education for the fathers. These differences in years of education between groups were not found to be statistically significant ($t(1,16) = 1.81$, $p = .09$, for mothers; $t(1,16) = .61$, $p = .55$, for fathers).

2.2 Procedure

The procedures used in this study have been described in detail elswhere (Rvachew, Slawinski, Williams, & Green, 1995) and will be summarized here.

All children visited the audiology department at the Alberta Children's Hospital for approximately one hour at ages 6, 9, 12, 15, and 18 months. All assessments were conducted within 2 weeks of the birthdate, except for 3 instances where the assessment occurred 3 weeks after the birthdate (these exceptions occurred for children in the Early Onset group, 2 at 6 months and 1 at 12 months of age). In most cases hearing and impedance measures were obtained first and then a taped speech sample was obtained immediately thereafter. Occasionally the speech sample was obtained on a separate day, within one week following the audiology assessment.

The auditory sensitivity and middle ear impedance measures were conducted by a pediatric audiologist. The speech and language assessments and analysis of the speech samples were completed by the first author, a speech-language pathologist.

2.3 Measures and Equipment

Audiology Assessment. Visual reinforcement audiometry (VRA) was used to assess auditory sensitivity to live voice and to warbled tones presented at 500, 1000, and 2000 Hz in the sound field. Tympanometry was performed to measure peak pressure and tympanic membrane compliance. At each visit ipsilateral reflexes were attempted at 1000 Hz at the previously recorded peak pressure value. Sound field threshold testing was accomplished in an Eckoustic double-walled sound chamber with the following equipment: Interacoustics Clinical Audiometer (model AC 30) and DALI speakers. Middle ear impedance measures were obtained with a GSI-33 Middle Ear Analyzer.

Speech Sample Collection. The speech samples were recorded in the Eckoustic double-walled sound chamber using a Sony Walkman Professional tape recorder and a Crown PZM-6D microphone. The mother was instructed to interact with her child in the usual manner. The mother and child were provided with the same set of quiet toys during each assessment. No effort was made to restrict the child's movements during recording sessions; rather the microphone was moved when necessary so that it was within 1 to 2 feet of the child, preferably positioned with the child facing the microphone (the pressure zone microphone used was capable of capturing almost all speech produced within the sound chamber, even when whispered). The recording session was continued until the child produced 60 utterances, which generally took between 10 and 30 minutes.

Speech Sample Analysis. Fifty consecutive utterances were selected from the tape, each meeting the following criteria: bounded by 1 second of silence, an audible inspiration, or adult speech; perceived to have a "unifying pitch contour" produced and recorded with sufficient loudness for coding; and not so obscured by adult speech or other noise as to prevent accurate coding. These utterances comprised both babble and occasional words but no effort was made to distinguish meaningful and nonmeaningful utterances for any of the analyses. Nonspeech sounds such as crying, laughing, burping, grunting etc. were excluded.

The speech samples were digitized using the Computerized Speech Research Environment (CSRE; Avaaz Innovations, Inc.) and the following hardware: an AST Premium 386C computer, DT2821 D/A, A/D board (12 bit), and a TTE 411AFS amplifier and antialiasing filter. The utterances were digitized at a sampling frequency of 20 kHz, low pass filtered at 10 kHz, and then submitted to Autoregressive Sprectral Estimation using a 128 millisecond (ms) analysis window, 128 Hz frequency bands, preemphasis, and a Hanning window.

The frequency of the first and second formants was determined for each vowel contained within a canonical syllable (Oller's 1986 criteria for canonical syllables were used, with a focus on the requirement for formant transitions with durations between 25 and 120 ms, normal phonation of the syllable nucleus, and syllable durations between 50 and 500 ms). When the nucleus of a syllable was a diphthong, the frequency spectrum was obtained for the first vowel only. Spectra were measured from the spectrograms for 10 millisecond segments located at the juncture of the first and second thirds of the steady state portion of the syllable, when appropriate. In many cases the segment most likely to yield a valid result was selected by eye. Often the formants contained gaps caused by intermittent breathiness or harshness in the infants' voices and it was necessary to avoid such gaps. This was especially true for the second formant which is often quite low in energy in infant vowels. This problem is reflected by better reliability for F1 than F2 frequency analyses. For example, the difference between intercoder judgments was less than 10 Hz for 78% of F1 judgments but were this close for only 55% of F2 judgments. The difference between intercoder judgements was less than 100 Hz for 93% of F1 judgements and 79% of F2 judgements.

In this study, the vowel formant analysis was restricted to canonical utterances, following the procedures used by de Boysson-Bardies et al. (1989) in their cross-linguistic study of infant vowel production. Although these authors do not justify their utterance selection criteria, some practical problems were solved by excluding vowel-only utterances. For example, it is not unusual for FRN utterances to be very long and to contain considerable variation in vowel identity throughout the utterance. In this case it is not possible to characterize the utterance by a single set of vowel formants. Canonical syllables by definition are restricted in duration to the range between 50 and 500 milliseconds and tend to represent a single monophthongal or diphthongal vowel.

3. RESULTS

3.1 Audiology Assessments

The age of onset of OM (as reported by the parent and confirmed by a physician) varied from 1 to 6 months for the Early Onset group. Four children in the Late Onset group experienced no identified episodes of OM during the course of the study. The remaining children in the Late Onset group were treated for their first known ear infection between 9 and 12 months of age. The Late Onset group received a total of 9 antibiotic prescriptions while the Early Onset group received a total of 55 prescriptions, for treatment of OM during the period birth through 18 months of age. Middle ear histories for individual subjects are shown in Appendix 1. Three infants in the Early Onset group were referred to an otolaryngologist at approximately 12 months of age, and two of these infants received bilateral myringotomies with insertion of ventilating tubes between the ages of 15 and 18 months. These data strongly suggest a more severe history of OM for the Early Onset group in comparison with the Late Onset group.

The mean Speech Reception (SRT) and Pure Tone Average (PTA) thresholds, averaged across all 5 assessments, were as follows: 10.88 (SRT; LO group); 12.22 (SRT; EO group); 21.04 (PTA; LO group); 22.06; EO group). The tympanometric assessments revealed 7 abnormal ears for the LO group and 14 abnormal ears for the EO group during the period 6 through 18 months of age. None of these between group differences in middle ear function or hearing ability were found to be statistically significant however.

3.2 Vowel Formant Analyses

The frequency of the first and second formants of all vowels contained within canonical syllables were determined. These values were used to calculate the following for each sample collected at 9, 12, 15, and 18 months: mean F1 frequency (*M* F1), standard deviation of the F1 frequencies (*SD* F1), mean F2 frequency (*M* F2), standard deviation of the F2 frequencies (*SD* F2), and the geometric mean of the F2/F1 ratios (*M* F2/F1). These values were not determined for the 6 month samples because many babies produced no canonical syllables at that age. The mean values for each group as a function of age are shown in Table 1. Separate ANOVAs were performed for each variable (i.e., *M* F1, *M* F2, *SD* F1, *SD* F2, *M* F2/F1). In each case the age of OM onset (LO or EO) was the between-groups variable and the age of the infant at time of assessment (9, 12, 15, or 18 months) was the within-groups variable.

Table 1. Mean and Standard Deviation of F1 and F2 Frequencies for all Vowels in Canonical Syllables by Age and Group (in Hz)

Variable	Age (in months)			
	9	12	15	18
LO Group				
M number of vowels analyzed per sample	17.5	23.5	32.0	34.4
M F1	927	877	908	885
SD of F1	224	232	199	244
M F2	2451	2488	2277	2367
SD of F2	456	567	612	724
M F2/F1	2.76	2.92	2.50	2.71
EO Group				
M number of vowels analyzed per sample	10.0	15.5	22.0	25.4
M F1	908	889	930	927
SD of F1	161	202	206	244
M F2	2539	2538	2341	2319
SD of F2	453	475	510	516
M F2/F1	2.91	2.85	2.51	2.60

These analyses revealed no age- or group-related variation in mean F1 freqencies, mean F2 frequencies, standard deviation of the F1 frequencies, or the mean F2/F1 ratio. The standard deviation of the F2 frequencies showed a significant increase with age of infant [$F(3,48) = 3.68$, $p = .0179$], as is shown in Figure 1 (with individual data shown in Appendix 2).

Figure 1 also suggests a smaller age-related increase in the standard deviation of F2 for the EO group, relative to the LO group. However, this trend was not statistically significant [$F(1,16) = 3.133$, $p = .0927$]. A significant between-groups difference was not obtained because of a large amount of within-subject variability in this variable for the EO group. The variability in the *SD* of F2 values for EO infants occurred, in part, because of the large between-group differences in the numbers of vowels available for analysis. The EO group produced significantly fewer canonical syllables per speech sample, and in some instances the *SD* of F2 was unusually large because only a small number of vowels were available for analysis; for example, the standard deviation of F2 was 939 Hz for one EO subject at 9 months of age, but only 2 canonical utterances were produced in this speech sample. A post hoc comparison of the standard deviation of F2 for 18 month samples was conducted. The standard deviation of F2 was significantly larger for the LO group in comparison with the EO group ($t(16) = 2.97$, $p = .005$, one-tailed) at 18 months of age. This analysis was possible because the mean number of analyzable vowels per sample was reasonably large for both groups at this age (34.4 for the LO group and 25.4 for the EO group), and not significantly different ($t(16) = 1.53$, $p = .07$, one-tailed).

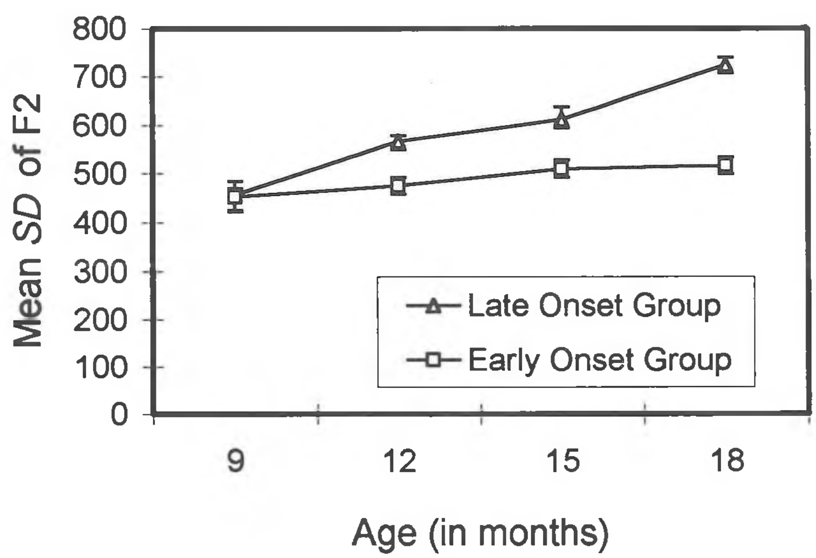
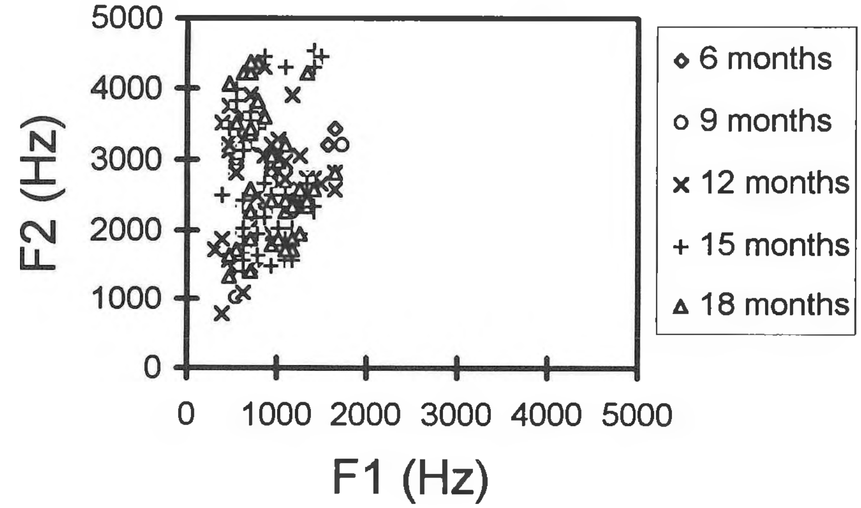


Figure 1. Mean standard deviation of the F2 frequencies as a function of age at time of assessment and group. Standard errors are indicated by error bars.



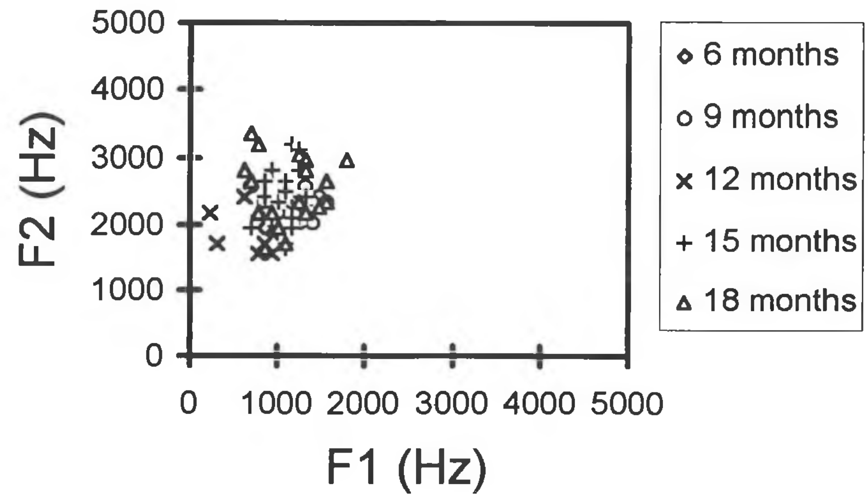


Figure 2. The top panel above shows the normally developing vowel space observed for one Late Onset subject, with the typical age-related increase in the range and standard deviation of F2 frequencies. The bottom panel shows the relatively restricted vowel space observed for one EO subject.

The standard deviation of the F2 values was found to be unusually small (more than one standard deviation below the mean *SD* for all 18 infants for a given age level) for 8 Early Onset samples. A restricted vowel space was also observed for 2 samples produced by Late Onset infants who developed recurring OM at 9 months of age. An example of a restricted vowel space, compared with a normally developing vowel space, is shown in Figure 2.

4. Discussion

Most of the infants in the current study demonstrated a pattern of similar development to those infants that were observed in the studies of normal development that were summarized in the introduction (i.e., Buhr, 1980; Kent & Bauer, 1985; Kent & Murray, 1982; Roug et al., 1989). Developmental changes in the center of the vowel space as reflected by the mean F1 and mean F2 values were not observed. When averaged across groups and sampling intervals for the period 9 through 18 months of age, the mean F1 was 906 Hz and the mean F2 was 2415 Hz. These mean F1 and F2 values are similar to but slightly lower than those reported by Kent and Murray (1982), perhaps reflecting the older age and larger vocal tracts of the infants studied here. Alternatively, the differences in F1 and F2 values across studies may be due to differences in acoustic analysis procedures or vowel sampling procedure: isolated vowels were excluded from analysis in this study, but included by Kent and Murray (1982).

Kent and Murray (1982) observed an increase in the range of F1 values between 3 and 6 months of age. In this study of infants aged 6 through 18 months of age, no age related changes in the standard deviation of F1 frequencies was observed, suggesting that rapid development in this dimension of the vowel triangle occurs very early in life.

In constrast to the findings for F1, most of the infants demonstrated an age-related increase in the range of F2 values. When considering the 9 month samples produced by LO infants, the F2 values that were one standard deviation on either side of the mean were 1995 Hz and 2907 Hz. At 18 months the corresponding F2 values for the LO group were 1643 Hz and 3091 Hz. The consistency of this pattern, both here and in other studies, serves to highlight those instances where the infant failed to show the expected increase in the range of F2 values with age (see Figure 2 above). One EO subject actually showed a decline in the range of F2 values for vowels produced within canonical syllables. This restriction in the size of the vowel space is qualitatively similar to findings for infants with sensory neural hearing losses in the moderate to profound range of severity (Carney, in press; Kent et al., 1987).

As noted earlier, developmental changes in infant speech production abilities are typically attributed to anatomical and neurophysiological maturation of the articulatory system. This study, and others with hearing impaired subjects or cross-language samples, highlight the importance of the auditory environment in early speech development.

The auditory environment is also important to the development of the infant's speech perception abilities. Infants begin learning to respond preferentially to many language-specific aspects of the ambient language very soon after birth. For example infants as young as 4 days old growing up in French-speaking homes can discriminate French from Russian, but not Italian from English (Jusczyk & Bertoncini, 1988). This developing preference for native language speech parameters, along with the support of adult caregivers, ensures that the child receives the kind of auditory input that is necessary for the development of a set of language specific templates that represent all of the relevant phonetic categories. By six months of age, infants demonstrate knowledge of language-specific vowel categories (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Polka & Werker, 1994). By the end of the first year of life the infant has lost the ability to respond to at least some non-native consonant contrasts (Werker & Tees, 1984). Thus, improvements in children's production accuracy throughout infancy and early childhood can be attributed in part to a gradually improving match between the child's perceptual categories and adult perceptual categories, and between the child's perceptual categories and the child's articulations.

It is not surprising that profound hearing loss interferes with this developmental process. The demonstrated impact of OM on early phonetic development might not be expected however, especially for vowels which are characterized by relatively strong and low-frequency formants. An episode of middle ear effusion may or may not be associated with elevated hearing thresholds. When hearing loss does occur, it is typically very mild (Fria, Cantekin, & Eichler, 1985; Roland, Finitzo, Friel-Patti, et al., 1989). For infants, speech awareness thresholds average between 23 and 27 dB and ABR thresholds average approximately 30 dB, during an episode of OM. For older children with OM, the median pure-tone-average threshold is only 23 dB although thresholds exceeding 40 dB occur in ten percent of cases. The best thresholds are observed at 2000 Hz while thresholds at other frequencies tend to be five to ten dB higher. Remember, however, that infant-produced vowel formants tend to be relatively high frequency and low in energy. OM may well disrupt the child's access to his or her own speech; in turn, the child's efforts to actively match vocal output to internalized phonetic categories will be impaired.

Nozza (1988) has shown that infant minimal response levels are 15 to 25 dB higher than minimal response levels observed for children and adults, and consequently OM-related hearing impairment can also be expected to impact on the infant's processing of adult produced speech. Performance versus intensity functions for speech discrimination by adults and infants show that a 10 to 20 dB hearing loss would not impact adult performance, but would lower infant performance to chance level responding.

Another important characteristic of OM-related hearing loss is that it may occur unilaterally or bilaterally. Pillsbury, Grose, & Hall (1991) speculated that unilateral losses interfere with the normal development of binaural processing abilities, thus accounting for the smaller Binaural Masking Level Differences observed in children with OM histories. Binaural processing is important to the child's ability to localize sound and to process speech in the presence of competing noise. Children with OM histories have been observed to have difficulty with binaural processing even when middle ear function and hearing acuity is normal.

Finally, the fluctuating nature of OM-related hearing loss may lead to both poor phonetic perception abilities and poor selective auditory attending skills. Inconsistent auditory input will make it difficult for the infant to discover the acoustic cues that characterize different phonetic categories. Inefficient templates that include irrelevant features or that exclude critical features have been shown to negatively impact on visual search skills (Duncan & Humphreys, 1989). It is hypothesized that inefficient auditory templates have a similar effect on selective auditory attention. Fuzzy auditory templates for phonetic categories will also interfere with phonetic development by providing an imprecise "target" for the child's articulations.

Numerous studies have shown that OM during infancy has a negative impact on language development later in life. When compared to children who have negative or minimal histories of OM, those children who have suffered recurring or chronic OM have demonstrated difficulties with speech perception skills, central auditory processing, phonological abilities, and language development (e.g., Menyuk, 1986).

Prospective studies have found that the risk of negative speech and language outcomes increases with earlier age of onset and a greater number of episodes of middle ear effusion. For example, Teele, Klein, and Rosner (1984) found that time spent with OM during the first 12 months of life was strongly correlated with language performance at age 3 years, while time spent with OM during the second and third years of life did not seem to impact on language abilities. The findings reported here support the conclusion that the long-term impact of OM on language development originates in infancy. Until recently babbling has been viewed as a reflexive, motoric behavior of little linguistic importance (cf. Locke, 1983). However, it appears that babbling may be an important, if not critical, phase in language development.

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7. Appendices

Appendix 1. Number of Antibiotic Prescriptions for Treatment of Otitis Media (#P) and Number of Ears Judged to be Abnormal by Tympanometry (#AE) at Each Assessment for Each Infant

	Age at Time of Assessment (in months)									
	6		9		12		15		18	
	#P	#AE	#Ps	#AE	#Ps	#AE	#Ps	#AE	#Ps	#AE
LO 1	0	0	0	0	0	0	0	0	0	CNT
LO 2	0	0	1	0	1	0	0	0	0	0
LO 3	0	0	0	1	3	0	0	0	0	0
LO 4	0	0	0	0	0	0	0	0	0	0
LO 5	0	0	0	0	0	0	0	0	0	0
LO 6	0	0	0	0	1	0	0	0	0	0
LO 7	0	0	0	1	0	2	1	1	0	0
LO 8	0	0	0	0	2	0	0	0	0	0
LO 9	0	0	0	1	0	1	0	0	0	0
Total	0	0	1	3	7	3	1	1	0	0
EO 1	4	2	1	0	1	2	6	1	0	VT
EO 2	1	2	1	0	0	1	0	0	2	0
EO 3	1	0	0	2	0	0	1	0	0	0
EO 4	3	0	0	0	2	0	0	0	0	0
EO 5	3	0	0	0	1	0	0	0	2	0
EO 6	1	0	1	0	1	0	0	0	0	0
EO 7	3	0	0	0	0	0	2	0	0	0
EO 8	6	2	1	2	0	0	0	0	0	0
EO 9	2	0	3	0	1	0	5	0	0	VT
Total	24	6	7	4	6	3	14	1	4	0

Note. LO = Late Onset group; EO = Early Onset group; CNT means that tympanometry could not be tested for this infant (because he would not cooperate for testing); VT refers to bilateral ventilating tubes.

Appendix 2. Standard Deviation of the Second Formant of Vowels Produced in Canonical Syllables at Each Assessment for Each Infant

	Age at Time of Assessment (in months)			
	9	12	15	18
LO 1	463	565	879	877
LO 2	411	606	619	748
LO 3	436	509	313	517
LO 4	339	605	855	799
LO 5	281	471	492	679
LO 6	546	781	899	895
LO 7	645	421	298	488
LO 8	370	622	494	738
LO 9	580	520	657	777
Mean	456	567	612	724
EO 1	283	489	478	727
EO 2	438	459	272	312
EO 3	328	549	727	326
EO 4	939	320	631	710
EO 5	211	736	554	445
EO 6	669	293	677	936
EO 7	258	483	563	479
EO 8	169	303	400	500
EO 9	785	644	320	470
Mean	453	475	510	516

Note. LO refers to infants in the Late Onset group while EO refers to infants in the Early Onset group.