Auditory Sensitivity and the Prelinguistic Vocalizations of Early-Amplified Infants

Deborah von Hapsburg
University of Tennessee, Knoxville

Barbara L. Davis
University of Texas at Austin

Purpose: Vocalization development has not been studied thoroughly in infants with early-identified hearing loss who receive hearing aids in the 1st year of life. This study sought to evaluate the relationship between auditory sensitivity and prelinguistic vocalization patterns in infants during the babbling stage.
Method: Spontaneous vocalizations of 15 early-identified infants with varying degrees of hearing sensitivity, from normal to profound hearing loss, were audiotaped and perceptually transcribed. Associations between the infant's unaided pure-tone average and the following vocalizations were explored: canonical babbling ratio, percentage of utterances containing canonical syllables, canonical syllable shapes, number of syllable sequences, and consonant-onset patterns in canonical syllables.
Results: Hearing sensitivity was significantly associated with the percentage of utterances containing canonical syllables, the vocalization types used in utterances, and canonical syllable shapes used by the infants.
Conclusions: Auditory sensitivity contributes significantly to the emergence of babbling patterns. In addition, there is a need for continued study of the vocalizations of infants with milder forms of hearing loss, because in this study, their vocalizations were highly variable despite having received early amplification.

KEY WORDS: infants, babbling, hearing loss, production

Vocalization emergence during the canonical babbling period results from a complex process involving coordination of multiple subsystems. In particular, neurophysiologic–motor, tactile, proprioceptive, and perceptual factors have been noted as contributing to vocal patterns (Eilers & Oller, 1994; Goffman, Ertmer, & Erdle, 2002; Oller & Eilers, 1988; Stoel-Gammon & Otomo, 1986). Each of these subsystems varies in the extent to which it contributes to the observable properties of vocalization development. Complex systems, such as the production system, are often not easily studied, because parts of the system cannot be isolated from one another. Contributions of auditory sensitivity to the emergence and organization of vocal patterns during the canonical babbling period have not been thoroughly detailed in very young infants who have been identified with hearing loss in the first year of life. To describe fully typical production, it is important to identify how the emergent properties of vocalizations in canonical babbling may be influenced by auditory sensitivity. Studies of vocalization patterns in infants with varying degrees of hearing loss can provide important information about the relative contribution of production and perception factors to prelinguistic vocalization development. In addition, this information can support the development of outcome measures for infants with hearing loss who are receiving amplification early in the first year.

The process of early speech acquisition from the onset of canonical babbling has been widely described for hearing infants through perceptual–transcription studies (Boysson-Bardies & Vihman, 1991; Roug, Landberg, & Lundberg, 1989; Vihman, Ferguson, & Elbert, 1986). Canonical babbling begins at approximately 6–8 months of age (see Oller, 2000, for a review) and is characterized by the production of repetitive, syllable-like output (i.e., [*baba*] or [*daedae*]). Perceptually, one of the most striking characteristics of canonical babbling is its sudden onset and rhythmicity as it sounds strikingly speech-like. Oller (1986) noted the following perceptual properties of canonical babbling: (a) at least one fully resonant nucleus (i.e., vowel with an identifiable quality, excluding highly nasalized vowels), (b) one nonglottal margin (consonant other than glottal consonant), (c) duration of syllable and formant transitions that are perceptually consistent with mature syllable production, and (d) normal phonation and pitch range.

Babbling behaviors have been described in a number of ways. Oller and Eilers (1988) used the canonical babbling ratio (CBR)—the number of canonical syllables per total number of utterances in a sample—to describe when the infant had entered into the "canonical babbling stage." A CBR of 0.2 or greater indicates that the infant is effectively in the babbling stage. In addition, other aspects of canonical syllables have been explored. For example, Kent and Bauer (1985) studied the most frequent syllable shapes and vocalization types used by infants during this period. Syllable shapes describe the combination of consonants (C) and vowels (V) that make up the syllable. For example, a syllable that is made of a consonant followed by a vowel is described as having a *CV shape*. Similarly, a syllable that is made up of a consonant–vowel–consonant sequence is referred to as having a *CVC shape*. Kent and Bauer found that the CV shape was predominate over VCV, VC, and CVC shapes and that, during this period, infants still used an abundance of singleton vowels (SVs). In addition, Mitchell and Kent (1990) studied the sequential structure of utterances produced by infants and found that monosyllabic CV vocalizations accounted for 19% of the canonical syllable types, whereas multisyllabic utterances only accounted for 11% of infant utterances. Within CV syllables, the consonants used at the onset of CV canonical syllables have been studied as well. Davis and MacNeilage (1995) found that during the babbling period, infants showed a predominance of coronal onsets over labial onsets, but during the first-word period, infants showed a reversed pattern. Segmental inventories have also been detailed for this vocalization period (Boysson-Bardies & Vihman, 1991; Davis & MacNeilage, 1995; Roug et al., 1989; Vihman et al., 1986). The most frequently observed consonant phone qualities were oral stops (e.g., labial and coronal stops), followed by nasals (e.g., /m/, /n/) and glides.

Researchers (Davis & MacNeilage, 1995; Green, Moore, & Reilly, 2002) have suggested that the primary determinants of early babbling patterns in speech acquisition are motor-system factors. Studies of the underlying neurophysiological development of motor control during this period have shown that the mandible develops before other articulators and achieves maturity or adult-like characteristics between 1 and 2 years of age, prior to any other articulator, including the upper lip and lower lip (Green et al., 2002). Transcription-based studies (Davis & MacNeilage, 1995) of the emergence of syllable organization in infant babbling have also supported the proposal that canonical babbling patterns are motivated primarily by mandibular oscillations without independent movements of other articulators within syllables. Thus, the mandible provides a relatively mature and stable structure that infants use to develop syllable-like behaviors at the onset of canonical babbling. Cross-linguistic studies of infant babbling have also suggested that the primary system contributing to early speech patterns is the motor system and that perceptual factors contribute to a lesser extent. Prior to 10 months of age and regardless of ambient language, infants tend to produce consonant qualities, including (a) labial and coronal place and (b) stop (oral and nasal) and glide manner of articulation (Boysson-Bardies & Vihman, 1991; Davis & MacNeilage, 1995; Roug et al., 1989; Vihman et al., 1986). At some point after 10 months of age, perceptual influences from the ambient language are reflected in infants' production patterns (e.g., Boysson-Bardies & Vihman, 1991). This lack of apparent ambient language influence before the late babbling and early speech periods suggests that hearing infant vocalizations are initially more influenced by the production system (motor constraints) than by perceptual input (Davis & MacNeilage, 2000).

The role of auditory feedback in the acquisition and maintenance of speech vocalizations has been studied in adults and children. Respiratory and kinematic studies of the effects of hearing loss on speech patterns in older children and adults with hearing loss have shown that reduced auditory feedback contributes to disordered segmental and prosodic patterns after speech has been acquired. Speech of older children with profound hearing loss has been shown to exhibit aberrant breathing patterns, inappropriate levels of nasality, and poor timing of syllable sequences (Higgins, Carney, McCleary, & Rogers, 1996; Tye-Murray, 1991). Even short-term interruptions in auditory feedback appear to result in alternate patterns of vowel production (Svirsky & Tobey, 1991). However, these studies on older children and adults do not demonstrate the contribution of auditory sensitivity during the earliest periods of speech acquisition.

In addition, landmark infant vocalization studies of the 1980s and early 1990s unequivocally demonstrated that early-vocalization emergence is subject to the influence of hearing sensitivity (Eilers & Oller, 1994; Oller & Eilers, 1988; Stoel-Gammon, 1988; Stoel-Gammon & Otomo, 1986). Canonical babbling is often delayed in infants with hearing loss compared with hearing infants (Eilers & Oller, 1994; Oller & Eilers, 1988). Hearing infants produce more monosyllabic sequences than di- and polysyllabic sequences and show preferences for CV and CVC syllable shapes during the canonical babbling period (Davis & MacNeilage, 1995; Kent & Bauer, 1985). However, no empirical studies have explored the use of syllable shape, percentage of canonical syllables in an utterance, and consonant onset in canonical CV syllables in early-identified infants with hearing loss. McCaffrey, Davis, MacNeilage, and von Hapsburg (2000) phonetically transcribed segmental and syllabic patterns in 1 profoundly hearing-impaired child who received a cochlear implant at 24 months. Prior to implantation, the infant produced predominantly SVs (mostly central) and consonants (mostly prolonged labial–nasal qualities). She had few CV syllable shapes, and had very few disyllabic vocalizations. At 6 months postimplantation, her repertoire still included SVs but also showed an increase in the number of CV syllables, suggesting a codependence of hearing- and production-system factors in canonical syllable emergence.

The codependence of production system and perceptual influences on vocalization organization was also highlighted by Goffman et al. (2002), who studied effects of change in auditory experience on motor control in 1 child, prior to and after she received a cochlear implant, using movement kinematics. Before implantation, the infant's movement variability was low, suggesting that her movement diversification was limited. After gaining experience with an implant, the infant's movement variability increased, allowing the her to explore a number of possible speech-related movements. These findings suggest that auditory sensitivity may contribute to movement patterning and that changes in auditory sensitivity are potentially associated with measurable diversification in the production system. These studies highlight the importance of early auditory feedback to the speech-acquisition process and suggest that multiple subsystems are recruited for the assembly of speech-like vocalizations. Precise data on the level of auditory sensitivity required for instantiation of prelinguistic speech-like syllable patterns are not available in children who have received hearing aids in the first 6 months of life. Few studies of vocal development in infants with hearing loss have detailed the effect of hearing loss on the emergence of various aspects of canonical syllable patterns, specifically in infants with milder hearing loss. Studies have mainly focused on age of babbling onset, CBR (Eilers & Oller, 1994; Oller & Eilers, 1988), and segmental inventories regardless of syllabic context (e.g., Stoel-Gammon & Otomo, 1986).

In the present study, we evaluated the relationship between auditory sensitivity and vocalization patterns in infants with 6 to 12 months of early hearing-aid experience. The contribution of auditory sensitivity to the organization of utterances and canonical syllable patterns was examined in 15 infants with hearing sensitivity ranging from normal sensitivity to profound hearing loss. Associations between hearing sensitivity, as estimated by the unaided pure-tone average (PTA; the average of thresholds at 500, 1000, and 2000 Hz), and vocalization patterns traditionally studied in typically developing infants were explored. We predicted that PTA would be significantly associated with the vocalization patterns observed, suggesting that interactive sensory- and production-system variables contribute to the vocalizations observed in the earliest phases of vocalization emergence. We evaluated this prediction for each of the following vocalization patterns: (a) CBR and percentage of utterances containing canonical syllables, (b) vocalization types within utterance strings (i.e., singletons [vowel- or consonant-like qualities]), glottal syllables (GSs; those with glottal margins), and canonical syllables (those with nonglottal margins), (c) syllable shapes (CV, VC, CVC, VCV), (d) number of consecutive canonical syllable sequences in an utterance (mono-, di- or polysyllabic), (e) consonant onset within canonical syllables of CV shape, and (f) consonant place in canonical syllables. These measures were chosen primarily because they have been extensively studied in typically developing infants and offer a concrete method by which vocalization development in infants with hearing loss can be effectively compared. It is likely that these variables are not independent of one another. For example, the measure of consonant segments at the onset of CV canonical syllables and consonant segments appearing in any context is related, as the broader analysis of consonant segments appearing in any context includes those segments in CV shapes. Although there may be some degree of redundancy among these particular variables, they have not been examined in one set of infants, and, therefore, the overriding importance of one variable over another is not clear.

Method

Participants

Fifteen infants with PTAs ranging from 25 dB HL to 120 dB HL in the better-hearing ear participated. Four infants exhibited hearing sensitivity within normal limits in at least one ear as suggested by soundfield

Table 1. Age characteristics of infants: Age at time of initial fitting of amplification (AA), chronological age (CA), and hearing age (HA) at the time of study.

Infant initials	Gender	AA (months)	CA (months)	HA (months)
		Normal hearing		
C.	F	—	12.0	12.0
M.	M	—	14.0	14.0
N.	M	—	11.0	11.0
R.	F	—	12.0	12.0
Total			49.0	49.0
M			12.3	12.3
SD			1.7	1.7
		Mild-to-moderately-severe hearing loss		
C.R.	M	5.0	13.0	8.0
J.H.	M	7.0	15.0	8.0
N.L.	M	6.5	11.0	4.5
A.M.	M	7.0	14.0	7.0
E.C.	M	2.5	7.0	4.5
A.W.	M	1.8	12.0	10.8
Total		29.8	72.0	42.8
M		4.9	12.0	7.1
SD		2.3	2.8	2.4
		Severe-to-profound hearing loss		
G.W.	F	1.5	16.0	14.5
S.P.	F	1.5	13.0	11.5
M.B.	F	1.5	16.0	14.5
B.B.	F	4.0	19.0	15.0
L.B.	F	13.0	24.0	11.0
Total		21.5	88.0	66.5
M		4.3	17.6	13.3
SD		5.0	4.1	1.9

screening at 25 dB HL. Six infants had bilateral mild-to-moderately-severe sensorineural hearing loss. Five infants had bilateral severe-to-profound sensorineural hearing loss. Table 1 describes participant demographic characteristics. For purposes of description, the infants are grouped according to the PTA in the better-hearing ear as follows: *normal* (PTA = 25 dB HL), *mild-to-moderately-severe* (PTA = 26–70 dB HL), and *severe-to-profound* (PTA > 71 dB HL).

Infants with normal hearing. Data from 4 (male = 2, female = 2) infants with normal hearing who participated in a larger study of early speech acquisition reported by Davis and MacNeilage (1995) were used for comparison with the hearing-impaired groups (for more details on these infants, see Davis & MacNeilage, 1995). The average age of the hearing infants was 12.3 months (range = 11–14 months). This age range was chosen because it matched the average age of the infants with hearing loss and because it was the oldest age at which the hearing infants were still producing a predominance of canonical babbling. Only prelinguistic vocalizations were analyzed, although 2 infants (R. and N.) were entering the first-word stage, on the basis of parent report of spontaneous word use. Tokens believed to be words were omitted from analysis. All infants in this group passed a soundfield hearing screening at 25 dB HL for the frequencies 500–4000 Hz. These infants were followed longitudinally over a 3-year period and developed speech and language normally.

Infants with hearing loss. Data were collected for 11 (female = 4, male = 7) infants with bilateral sensorineural hearing loss. The 6 infants with bilateral mild-to-moderately-severe sensorineural hearing loss (*M* PTA = 47 dB HL in the better-hearing ear) were all boys. Table 2 shows the PTAs obtained for each ear for each participant. Because the infants were referred from multiple centers, there were varying amounts of audiological information available in each infant's record. Audiometric threshold information also varied, with some having only soundfield information at select frequencies and others yielding binaural, ear-specific data at many of the audiometric frequencies. Infant A.M. had missing information at 2-kHz bilaterally; therefore, a two-frequency PTA (500 Hz and 1000 Hz) was used to calculate his PTA. The average age at which the infants received their first hearing aids was 4.9 months. Average chronological age at the onset of the study was 12 months (range = 7–15 months). The average hearing age (i.e., time since hearing-aid fitting) was 7.1 months (range = 4.5–10.8 months).

Five infants with bilateral, severe-to-profound sensorineural hearing loss (*M* PTA = 106 dB HL in the better ear) participated (see Table 2 for auditory threshold information). Infants with severe-to-profound loss were, on average, 5 months older than those with mild-to-moderately-severe hearing loss or those with normal hearing. In addition, the hearing age of the infants with severe-to-profound hearing loss exceeded that of the infants with mild-to-moderately-severe hearing loss by approximately 5 months but approximated that of the infants with normal hearing. For some of the infants in the severe-to-profound group, no response was obtained at the limit of the audiometer, at some frequencies. Table 2 shows these as "no response" ("NR [120 dB HL]"), for Infants S.P., B.B., and L.B. The average chronological age of infants with severe-to-profound hearing loss was 17.6 months (range = 13–24 months), and their average hearing age was 13.3 months (range = 11–15 months). The average age at which they received amplification was approximately 4.3 months (range = 1.5–13.0 months).

Infants were referred to this study from three cities in the southern United States. All participants had hearing parents who used oral communication. All except for 1 infant (G.W.) were from English-speaking homes. Infant G.W. was from a bilingual Spanish–English-speaking home. None of the infants demonstrated severe motor or cognitive delays, although some showed mild motor delays on the basis of available testing.

Table 2. Auditory threshold information for infants with hearing loss.

Infant initials	Ear	Auditory thresholds in dB HL[a] 500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA	Best PTA
Mild-to-moderately-severe hearing loss							
C.R.	R	35	25	50	55	37	37
	L	40	35	45	50	40	
J.H.	R	70	75	60	70	68	40
	L	40	35	45	50	40	
N.L.	SF	35	40	45	55	40	40
A.M.	R	60	70	DNT	75	65[b]	65
	L	60	75	DNT	70	68[b]	
E.C.	R	35	55	65	95	52	52
	L	45	55	55	60	52	
A.W.	R	100	100	95	95	98	50
	L	50	50	50	65	50	
Group PTA							47
Severe-to-profound hearing loss							
G.W.	R	80	95	95	90	90	85
	L	85	75	95	95	85	
S.P.	SF	85	NR (120)	NR(120)	NR (120)	108	108
M.B.	R	95	105	100	90	100	100
	L	95	110	100	NR (120)	102	
B.B.	R	NR (120)	NR (120)	NR (120)	NR (120)	NR (120)	118
	L	NR (120)	120	115	120	118	
L.B.	SF	NR (120)	NR (120)	NR (120)	NR (120)	120	120
Group PTA							106

Note. SF = sound field. DNT = did not test. A three-frequency, PTA was calculated. When "no response" (NR) was obtained at the limits of the audiometer, a value of 120 DB HL was entered as the threshold for that frequency.

[a]American National Standards Institute (1989). [b]PTA estimated from thresholds at 500 and 1000 Hz.

All of the infants with hearing loss were attending oral–aural habilitation sessions at least once a week. A description of the severity of hearing loss for each infant was obtained from case histories and medical–audiological records provided by parents. Click and tone-burst auditory brainstem response audiometry was used for initial diagnosis and confirmation of hearing loss. All participants had hearing and hearing-aid evaluations performed by the audiologist at their local clinic within a month of data collection. Behavioral pure-tone information was obtained either in the soundfield or through headphones by the referring clinics. With the exception of 1 infant, all hearing aids were fit using probe microphone procedures (real-ear-to-coupler difference [RECD]) and the desired-sensation-level (DSL; Cornelisse, Seewald, & Jamieson, 1995) procedure. All participants wore behind-the-ear (BTE) hearing aids binaurally. Parents and the investigator monitored hearing-aid function (i.e., made sure the hearing-aid batteries were working, listened to the hearing aids, and monitored hearing use) immediately prior to data collection. Prior to data collection, hearing-aid batteries were tested and a listening check of the hearing aids was performed to determine function.

Data Collection Procedures

Recording. All infants were video- and audio-recorded and wore a wireless microphone (Audio Technica ATW-1030 or a Telex ProStar FM remote microphone) clipped to one shoulder of a bib specially made to hold the wireless receiver. All data except for 1 infant were recorded on digital audio recorders (Sony TCM-5000 or Tascam DA-P1). After the microphone and receiver were in place, infants were not typically aware of their presence. The investigator observed the infant and parent interact in their home, monitored the equipment, and interacted with the infant only as needed for equipment adjustments. The data for the hearing-impaired infants were collected by the first author, with the exception of 3 infants (B.B., M.B., and L.B.) whose data were collected by another aural habilitation specialist.

The amount of data collected for each infant varied according to parent availability and vocalization volubility. Data were collected at home or during aural habilitation sessions conducted in center-based environments. Data collection did not exceed a period of 1 month per child. A total of 869 (M = 145) min of data was analyzed

Table 3. Data collected, including number of minutes, utterance strings, canonical babbling ratio (CBR), and percentage of utterances containing canonical syllable presence (UCSP).

Infant initials	No. of min	No. of utterances	CBR	% UCSP
Normal hearing				
C.	60	394	1.03	65.5
M.	120	325	0.95	50.5
N.	120	249	1.34	68.7
R.	60	257	1.10	66.9
M	90	306	1.11	62.9
SD	34.6	67.7	0.16	8.4
Mild-to-moderately-severe hearing loss				
C.R.	152	254	0.93	72.8
J.H.	90	385	2.12	76.9
N.L.	119	285	0.58	40.4
A.M.	177	377	1.14	61.0
E.C.	181	297	2.08	74.7
A.W.	150	361	0.38	29.1
M	144.8	326.5	1.21	59.2
SD	34.9	54.8	0.74	20.0
Severe-to-profound hearing loss				
G.W.	148	466	2.07	69.5
S.P.	233	188	0.22	27.2
M.B.	70	415	0.57	17.6
B.B.	250	468	0.08	0.7
L.B.	120	281	0.37	26.3
M	164.2	363	0.66	28.3
SD	76.1	124.2	0.81	25.4

for the group of infants with mild-to-moderately-severe hearing loss. For the group of infants with severe-to-profound hearing loss, 821 (M = 164) min were analyzed. The data for infants with hearing loss were compared with a total of 360 (M = 90) min obtained from hearing infants. Table 3 shows the number of minutes, utterances, CBR, and the percentage of utterances that contained at least one canonical syllable for each infant. All infants except for 1 were in the canonical babbling stage according to the criterion (0.2) described by Oller and Eilers (1988).

Transcription. Data were transcribed using the International Phonetic Alphabet (IPA; International Phonetic Association, 1999) system of notation. The primary investigator transcribed all data collected for infants with hearing loss with the exception of 1 infant. All tokens were digitized and played back through Sony MVR-V500 headphones. Video was used only to corroborate unclear tokens on the audio recordings or to verify lip rounding when there was uncertainty. Tapes for the infants with normal hearing from Davis and MacNeilage's (1995) research were retranscribed to add nonsyllabic tokens (singletons and GSs as well as untranscribable vocalizations). If the primary author disagreed with the original transcription on canonical syllables, the transcription was changed to reflect the principal investigator's perception. This procedure was intended to reduce the amount of variability across transcribers.

Broad transcription was used for all data. Designation of canonical syllables was based on perceptual judgment. The perceptual definition provided by Oller and Eilers (1988) for a canonical syllable was used. Briefly, canonical syllables had (a) at least one fully resonant nucleus (i.e., vowel with an identifiable quality), (b) one nonglottal margin (consonant other than glottal stop or glottal fricative), (c) duration of syllable and formant transitions that fit within the range of mature syllable production (perceptually), and (d) normal phonation and pitch range. Oller (1986) provided acoustic parameters for each of these aspects of the syllable. Acoustic analyses were not performed to verify categorization of canonical syllables. Therefore, it is possible that some slow-transition syllables, known as *marginal syllables,* were included in the analysis. Noncanonical vocalizations were perceptually judged as containing vowel-like or consonant-like qualities that did not meet the criteria for the well-formed syllable (i.e., SVs [e.g., /a/] or SCs [e.g., /m/, /v/]). CVs bounded by glottal consonants in initial or final position (i.e., /h/, ʔ]) were considered GSs.

For consonants, four places of consonantal articulation were specified: labial (i.e., [p, b, m, w, β]), coronal (i.e., [t, d, n, z, s, ʒ, θ, ð, ʃ, tʃ, dʃ, l, j]), dorsal (i.e., [k, g, ŋ, x]), and glottal (i.e., [h, ʔ]). Although some uvular consonants were transcribed, they represented less than 5% of each infant's inventory and, thus, were not included in the place analysis. Consonants were also classified in terms of the following manner categories: plosive (i.e., [p, b, t, d, k, g, ʔ]), nasal (i.e., [n, m, ŋ]), fricatives and affricates (i.e., [β f, v, z, s, ʒ, θ, ð, ʃ, tʃ, dʃ, h, x]), and approximants (i.e., [l, ɹ]). All phones were transcribed regardless of whether they appear in the English language. Vowel front–back dimensions were specified as *front* (i.e., [i, ɪ, e, ɛ, y, æ]), *central* (i.e., [ə, ʌ, a]), or *back* (i.e., [u, ʊ, o, ɔ, ɑ]). Vowels were also classified by height as *high* (i.e., [y, i, ɪ, u, ʊ]), *mid* (i.e., [e, ɛ, o, ɔ, ə, ʌ]), or *low* (i.e., [æ, a, ɑ]). Vocalizations separated by approximately 1 s were considered to be different utterances. Sound Studio Classic software (Kwok, 2001) was used to verify utterance boundaries. Global symbols (Oller, 1990) were used to categorize utterances that were not transcribable and included untranscribable nuclei (UNs), untranscribable consonants (UCs), and untranscribable vowels (UVs). If the primary transcriber could not determine the vocalic or consonantal quality of a sound or sequence, the token was classified as either UC or UV if produced in isolation. If an entire utterance was untranscribable, it was marked "UN." These tokens were highly ambiguous and could be described as garbled articulations, with little resonance or identifiable vocalic or consonantal qualities. Vegetative and reflexive sounds (e.g., cries, burps, grunts, coughs, and hiccups) were not transcribed. All transcribable vocalizations regardless of the mood (e.g., playful, complaining) were transcribed if they contained identifiable tokens (singleton consonants [SCs], SVs, marginal syllables [MSs], CV, VC).

Data Analysis

Transcribed data were analyzed using the Logical International Phonetics Program (LIPP; Oller & Delgado, 1990). LIPP analysis included (a) CBR; (b) the percentage of utterances containing at least one canonical syllable; (c) inventory of vocalization types within utterance strings such as SVs and SCs, GSs (h+V, ʔ+V), and canonical syllables (CV, VC, CVC, VCV, etc.); (d) inventory of canonical syllable shapes (CV, VC, CVC, and VCV); (e) number of syllable sequences (mono-, di- and polysyllabic); (f) consonant onset in canonical CVs (coronal, labial, dorsal); and (g) consonant place analysis of canonical syllables and GSs. A description of each follows.

Vocalization types within utterance strings. An inventory of utterances defined as a string of sequenced vocalizations (canonical syllables or noncanonical syllables) uttered in a single-breath group and bounded by 1 s of silence or parental utterance was generated. An utterance could contain any number of sequences. For example, an utterance could contain a string of syllabic vocalizations and singletons, such as [*ba ba ab a*]; sequences of singletons only, such as [*m: a a a*]; or a sequence that contained UNs mixed with canonical syllables and singletons (e.g., [*N di a*]) as long as they belonged to the one-breath group. The contents of each utterance string were classified into the following categories: singleton vocalizations such as SVs and SCs, GSs, those bounded by glottal consonants, and canonical syllabic (CS) output (CV, VC, CVC, VCV, etc.) bounded at the onset or offset by labial, coronal, and dorsal consonants. For example, the utterance containing [untranscribable, *di a*] was coded as *UN, CS, SV.*

Canonical syllable patterns. Utterances containing canonical syllables were further analyzed to obtain the number of syllable sequences in each utterance, canonical syllable shape, consonant onset in canonical syllables of CV shape, and consonant inventory appearing in any syllabic context. Only utterances containing canonical syllables were analyzed. For canonical syllable sequence analysis, the number of consecutive syllable sequences within each utterance was counted. If a vocalization string consisted of a single canonical syllable, it was classified as *monosyllabic* (i.e., [*ba*]). If it contained two consecutive syllables, it was classified as *disyllabic* (i.e., [*ba ba*]). Utterances with more than two canonical syllables were classified as *polysyllabic* (i.e., [*ba ba ba*]). Canonical syllables were further analyzed in terms of syllable shape (e.g., CV, VC, CVC, and VCV). Finally, consonant-onset inventories were based on the consonant onset of each initial CV canonical syllable, because these are the shapes most frequently occurring in hearing infants.

Statistical analysis. For purposes of analysis, the PTA for all infants in the normal-hearing group was assumed to be 25 dB HL. Similarly, for those infants who had no response to some frequencies, a threshold value of 120 dB HL was entered for analysis. The data are presented in tabular form. In addition, for each inventory analyzed (e.g., vocalization types, syllable shape), regression analyses were used to determine any significant associations between the infants' better ear, unaided PTA (dependent variable) and inventory type (e.g., canonical syllable presence, canonical syllable shape, number of canonical syllable sequences, consonant onset in canonical syllables of CV shape, and vocalization types within utterances). For example, for the analysis of syllable sequences, three regression analyses were performed, one for each of the sequences examined (monosyllabic, disyllabic, and polysyllabic). For each regression performed, a t value, p value, and R^2 value are reported when significance was obtained. A probability value of .05 was considered significant, and a Bonferroni correction was applied for each set of regression analyses to control for the possibility of Type I error. The analyses determined whether the relationship between PTA and the independent variables was significant across the 15 infants, not across the hearing-loss groups.

Results

Reliability

Twenty percent of each infant's tokens were randomly chosen and digitized on a digital audiotape (DAT). A phonetician with over 10 years experience transcribing hearing and hearing-impaired infant vocalizations retranscribed these tokens. Both the first author and the phonetician participated in biweekly transcription training sessions over a 2-year period. The second transcriber was blind to the hearing status of the infant producing the tokens, but the first transcriber was not. Reliability was determined on four parameters: (a) canonical versus noncanonical syllables, (b) canonical syllable shape, (c) vocalization types, and (d) consonant place–manner agreement.

Agreement on whether tokens were considered canonical or noncanonical was obtained first. The transcribers categorized each token within an utterance as canonical or noncanonical. For example, for an utterance such as [*a di*], the SV was considered a noncanonical token and [*di*] was considered a canonical syllable. The utterance was coded as [*noncanonical, canonical*]. If the second transcriber recorded [*ʔa ni*], it was coded as [*noncanonical, canonical*] and counted as 100% agreement. If the second transcriber recorded [*da ni*] as [*canonical, canonical*], one disagreement was counted. Agreement on this dimension ranged from 84% to 100% across infants. The overall mean agreement was 91%.

For each utterance in the 20% sample, the two transcriptions were compared to determine the level of agreement for vocalization types appearing within utterances (i.e., UN, SV, SC, GS, CS). Agreement varied from 66% to 96%, with an overall average of 75%. The most frequently occurring disagreements (50%) involved transcription of SVs as GSs (25%, usually [ʔ +*V*]) and vice versa (25%). The second most frequently occurring disagreement involved transcription of SVs as canonical syllables (18%). These disagreement patterns accounted for 68% of all disagreements (the remaining disagreements fell below 5% under different categories).

The third reliability analysis examined syllable-shape agreement when canonical syllables were transcribed. Agreement across infants varied from 60% to 95%, with an overall average of 80% agreement for syllable shapes. Analysis of the disagreements showed that in 28% of disagreements CVCs were transcribed as CVs, in 20% VCVs as CVs, and in 5% VCs as CVs. CVs and VCs were transcribed as nonsyllabic (23% and 7%, respectively) in 30% of cases. These patterns accounted for 83% of disagreements.

Only consonant agreement is reported here, because no analyses involved vowel production. Consonants were compared in place and manner. Agreement was calculated using a multidimensional analysis procedure discussed in Oller and Delgado (1990). Consonant agreement was 91% for both groups of infants with hearing loss.

A total of 5,002 utterance strings were analyzed. The hearing infants produced 1,225 (M = 306) utterance strings, infants with mild-to-moderately-severe hearing loss produced 1,959 (M = 326) utterance strings, and the infants with severe-to-profound loss produced 1,818 (M = 363) utterance strings. Table 3 shows the mean number of utterances for each infant and group. All subsequent analyses were based on these utterances.

Canonical Syllable Presence and CBR

All utterances were analyzed for the presence of canonical syllables to determine whether PTA was significantly associated with syllabic content appearing in utterances. Utterances containing true canonical syllables were separated from those utterances that did not contain canonical syllables (i.e., GSs or SVs). For example, when an utterance contained the sequence [*bab a a a*], it was counted as containing canonical syllable "presence." If an utterance contained [*a ʔa a*], the utterance was counted as having canonical syllable "absence." Approximately 63% (SD = 8.4%) of the utterances produced by infants with normal hearing and 59% (SD = 20.0%) of those produced by infants with mild-to-moderately-severe hearing loss contained at least one canonical syllable; only 28% (SD = 25.4%) of the utterances produced by infants with severe-to-profound hearing loss contained at least one canonical syllable. Table 3 shows the individual data for the percentage of utterances containing canonical syllable presence. The data for the infants with hearing loss have large variability compared with the infants with normal hearing. For example, 4 of the infants with hearing loss (C.R., J.H., E.C., and G.W.) produced a higher percentage of utterances containing canonical syllables than the normal-hearing infants. The association between the unaided PTA and the percentage of utterances containing canonical syllables across the infants was significant, $t(13) = -3.81$, $p < .00$, $R^2 = .53$, suggesting that PTA was a significant factor determining the percentage of utterances that contained at least one canonical syllable.

The CBR was also calculated for each infant. The ratio of the number of canonical syllables produced divided by the total number of utterances produced was calculated. CBRs ranged from 0.08 to 2.10. Only 1 of the 15 infants was not in the canonical babbling stage according to the 0.2 criterion. Infants with normal hearing and mild-to-moderately-severe hearing loss had higher CBRs on average (approximately 1.1 and 1.2, respectively) than infants in the severe-to-profound loss group, with an average CBR of 0.66 (see Table 3). An analysis of outliers performed using a jack-knife distance method showed only 1 infant (G.W.) to be an outlier regarding CBR (her CBR was in the range of normal). This method calculates the distance for each observation with estimates of the mean and standard deviations that do not include the observation itself. The data were analyzed with and without this participant's information to determine the extent to which she affected results. Without G.W., the regression analysis showed a significant relationship between CBR and PTA, $t(13) = -0.53$, $p = .03$, $R^2 = .35$, but was nonsignificant ($p = .10$) with G.W.'s data included. Infant G.W.'s data were not removed from the dataset in subsequent analyses. The outlier analysis did not identify any other infants as outliers, although there was large variability in performance across the infants with hearing loss.

Vocalization Types Within Utterances

An inventory of vocalization types within utterances was compiled to determine what types of vocalizations, in addition to canonical syllables, infants produced. A total of 12,914 individual tokens were analyzed (3,993 vocalization types for infants with normal hearing, 4,838 for infants with mild-to-moderately-severe hearing loss, and 4,083 vocalization types for infants with severe-to-profound hearing loss). For infants with normal hearing, approximately 12% of the inventory consisted of untranscribable tokens. SVs (15%) and SCs (9%) accounted for approximately 23% of their inventory, and GSs (those bounded by glottal stops or fricatives) accounted for approximately 8%. Canonical syllables including CV, VC, CVC, and VCV shapes accounted for 57% of utterance types within utterances. For infants with mild-to-moderately-severe hearing loss, 7% of the inventory consisted of untranscribable utterances. SVs (22%), and SCs (7%), accounted for approximately 29% of the vocalization types in utterance strings. GSs accounted for 15% of vocalization types, and canonical syllables accounted for 50% of vocalization types. For infants with severe-to-profound hearing loss, UNs accounted for 5% of the overall inventory. SCs, SVs, GSs, and canonical syllables accounted for 30%, 22%, 17%, and 26% of these infants' vocalizations, respectively. The variability for infants with hearing loss was higher than for infants with normal hearing. Table 4 shows that the variability increased with increasing hearing loss. Variability for infants with severe-to-profound hearing loss was higher across all the vocalization categories than the variability of infants with milder hearing losses.

To examine the relationships among PTA and vocalization types occurring within utterances, regression analyses were calculated with PTA as the dependent variable and SCs, vowels, and GSs each as independent variables. The PTA was significantly associated with SCs, $t(13) = 2.46, p = .03, R^2 = .32$. PTA was not associated with SVs or GSs.

Number of Consecutive Canonical Syllables in Utterances

Utterances containing canonical syllables were further analyzed for number of canonical syllables. Only utterances containing canonical syllables bounded by or containing labial, coronal, or dorsal consonants (e.g., CV, VC, CVC, and VCV) were analyzed. The number of consecutive syllables appearing within each utterance string was counted. A total of 2,466 utterances containing sequenced syllable-based output were analyzed: 765 for the hearing group, 1,153 for the mild-to-moderately-severe group, and 548 for the severe-to-profound group, respectively. For all three groups, monosyllabic utterances were dominant, accounting for 54%, 59%, and 65% of infants with normal, mild-to-moderately-severe, and severe-to-profound hearing sensitivity, respectively. Utterances containing disyllables accounted for 29%, 20%, and 18% of the respective inventories for infants with normal, mild-to-moderately-severe, and severe-to-profound hearing sensitivity. Last, polysyllabic sequences accounted for 17%, 21%, and 17% of each group, respectively (see Table 5). In the regression analyses, we found no significant relationship among PTA and the percentage occurrence of mono-, di-, and polysyllabic utterances in the corpora.

Table 4. Inventory of vocalization types in utterances, including untranscribable vocalizations (UVs), singleton consonants (SCs) and vowels (SVs), glottal syllables (GSs), and canonical syllables (CSs).

	Percentage inventory of vocalization types within utterances					
Infant initials	**UV**	**SC**	**SV**	**GS**	**CS**	**PTA**
			Normal hearing			
C.	16.37	6.84	8.90	3.18	64.71	25
M.	8.74	12.12	19.33	12.58	47.24	25
N.	14.83	7.50	10.12	5.76	61.79	25
R.	6.30	7.68	20.87	9.06	56.09	25
M	11.56	8.53	14.80	7.64	57.46	25
SD	4.81	2.42	6.17	4.08	7.69	0
			Mild-to-moderately-severe hearing loss			
C.R.	3.77	5.22	11.59	11.30	68.12	37
J.H.	6.52	2.53	10.03	12.15	68.76	40
N.L.	15.70	8.06	31.61	10.33	34.50	40
A.M.	3.20	4.93	20.41	22.36	49.08	65
E.C.	4.50	13.70	11.00	9.60	61.20	52
A.W.	5.67	8.00	46.33	24.56	15.44	50
M	6.56	7.07	21.83	15.05	49.52	47
SD	4.64	3.86	14.56	6.61	21.17	10.5
			Severe-to-profound hearing loss			
G.W.	4.36	8.92	13.98	5.06	67.67	85
S.P.	14.21	18.27	8.88	44.92	13.71	108
M.B.	3.18	6.08	35.39	32.40	22.95	100
B.B.	0.60	90.70	8.21	0.00	0.48	118
L.B.	1.25	23.94	45.64	3.49	25.69	120
M	4.72	29.58	22.42	17.18	26.10	106
SD	5.51	34.91	17.05	20.19	25.24	14.3

Canonical Syllable Shape

Canonical syllables were further analyzed in terms of syllable shapes (e.g., CV, VC, CVC, and VCV). Results are shown in Table 5. The total number of canonical syllables analyzed for normal-hearing infants was 1,485; for infants with mild-to-moderately-severe hearing loss, 2,430; and for infants with severe-to-profound hearing loss, 1,362. The CV shape was the most predominant shape in all three groups, accounting for 80%, 63%, and

Table 5. Canonical syllable patterns, including number of consecutive canonical syllables in an utterance (mono-, di-, polysyllables), syllable shapes (CV, CVC, VC, VCV), consonant onset in canonical CV syllables (labial, coronal, dorsal), and inventory of consonant place of articulation in canonical syllables (labial, coronal, dorsal, glottal [ʔ], [*h*]).

	Canonical syllable patterns (%)															
Infant	Syllable sequence			Syllable shape				Consonant onset in CVs			Consonant place					
initials	Mono	Di-	Poly-	CV	CVC	VC	VCV	Labial	Coronal	Dorsal	Labial	Coronal	Dorsal	Glottal [ʔ]	Glottal [*h*]	PTA
								Normal hearing								
C.	52.7	37.2	10.1	91.4	6.6	0.2	1.7	55.7	27.6	16.7	52.0	26.2	15.0	2.3	4.4	25
M.	62.8	20.1	17.1	89.3	5.8	2.6	2.3	38.6	54.6	6.8	33.3	38.1	4.5	4.1	20.0	25
N.	46.2	27.5	26.3	53.7	26.6	12.1	7.6	34.9	47.0	18.1	34.6	35.9	16.6	5.2	7.7	25
R.	55.2	31.4	13.4	83.5	9.1	2.8	4.6	18.4	70.0	11.6	19.6	54.6	10.9	1.6	13.3	25
M	54.2	29.1	16.7	79.5	12.0	4.5	4.0	36.9	49.8	13.3	34.8	38.7	11.8	3.3	11.4	25
SD	6.9	7.2	7.0	17.5	9.7	5.3	2.7	15.3	17.6	5.2	13.3	11.8	5.4	1.7	6.8	0
								Mild-to-moderately-severe hearing loss								
C.R.	78.4	18.4	3.2	82.6	10.6	4.2	2.6	83.5	14.2	2.3	66.4	10.7	3.9	12.7	6.3	37
J.H.	35.2	24.3	40.5	68.2	20.4	4.9	6.5	28.4	61.7	9.9	26.4	47.1	10.7	6.9	8.9	40
N.L.	76.5	12.2	11.3	58.4	15.1	9.6	16.9	86.2	10.7	3.1	59.0	8.4	5.2	19.9	7.5	40
A.M.	55.2	26.5	18.3	50.0	14.5	15.4	20.1	62.7	32.9	4.4	43.9	19.0	4.1	27.3	5.7	65
E.C.	28.8	25.3	45.9	62.7	19.1	10.5	7.7	7.0	84.4	8.6	10.4	62.3	10.3	11.4	5.6	52
A.W.	78.1	14.3	7.6	54.8	7.9	12.9	24.4	57.3	32.3	10.4	21.4	8.7	3.1	40.3	26.5	50
M	58.7	20.2	21.1	62.8	14.6	9.6	13.0	54.2	39.4	6.5	37.9	26.0	6.2	19.8	10.1	47
SD	22.5	6.1	17.9	11.6	4.8	4.4	8.6	31.2	28.5	3.6	22.1	23.0	3.3	12.4	8.1	10.5
								Severe-to-profound hearing loss								
G.W.	28.7	22.8	48.5	80.4	8.3	2.9	8.4	9.1	83.5	7.4	9.9	74.6	6.5	5.3	3.7	85
S.P.	72.7	24.3	3.0	63.0	3.7	13.0	20.3	9.8	68.2	22.0	11.3	13.3	3.5	53.1	18.8	108
M.B.	51.3	21.3	27.4	60.9	8.4	12.2	18.5	70.0	29.5	0.5	31.2	10.7	0.4	56.5	1.2	100
B.B.	100.0	0	0	25.0	0	75.0	0	100.0	0	0	100.0	0	0	0	0	118
L.B.	74.3	20.3	5.4	66.0	9.7	24.3	0	81.0	17.7	1.3	74.2	10.9	0.8	1.6	12.5	120
M	65.4	17.7	16.9	59.1	6.0	25.5	9.5	54.0	39.8	6.2	45.3	21.9	2.2	23.3	7.2	106
SD	26.8	10.0	20.7	20.5	4.1	28.7	9.8	42.0	35.0	9.3	40.1	29.9	2.8	28.9	8.1	14.3

59% of shapes for infants with normal, mild-to-moderately-severe, and severe-to-profound hearing sensitivity, respectively. The CVC was the next most prominent syllable shape for infants with normal and mild-to-moderately-severe hearing sensitivity, accounting for 12% and 15% of syllable shapes, respectively. For infants with severe-to-profound loss, CVC shapes accounted for only 6% of shapes. The second most prominent shape for these infants was the VC shape, accounting for 25% of syllable shape types. Regression analyses were used to examine the relationship between PTA and each of the four syllable shapes. A significant association was found between PTA and VC shapes, $t(13) = 2.9$, $p = .01$, $R^2 = .39$. No other syllable shape was associated with PTA.

Consonant Onset in Canonical CV Syllables

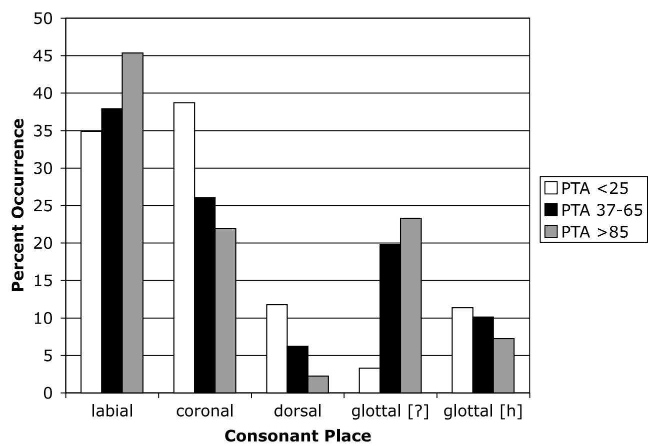
Because infants with normal hearing have a tendency to begin CV syllables with coronal consonants during babbling, we were interested in determining which consonants were used at the onset of the CV canonical syllable. An inventory of CV canonical syllables, classified by consonant onsets, was created for each infant. A total of 1,274 CV canonical syllables were analyzed for infants with normal hearing, 2,175 for infants with mild-to-moderately-severe hearing loss, and 1,236 for infants with severe-to-profound hearing loss. Syllable-onset preferences for infants with normal hearing were coronal (50%), labial (37%), and dorsal (13%). For infants with mild-to-moderately-severe hearing loss, onset preferences were as follows: 54% labial, 39% coronal, and 6% dorsal. Last, for infants with severe-to-profound hearing loss, syllable onsets were distributed as follows: 54% labial, 40% coronal, and 6% dorsal. Table 5 shows the consonant-onset data averaged across the infants in each group. Regression analyses found no significant association between the PTA and consonant-onset preference in canonical syllables of CV shape.

Consonant Place Inventories and Glottal Sequences [ʔ] and [h]

Prior literature on vocalization development in infants with hearing loss has reported that in terms of consonant inventories, the only consonant qualities that differentiate infants with hearing loss from infants with normal hearing is an overabundance of "glottal sequences," particularly glottal stop sequences with vowel-like elements (Oller, 1991). The glottal consonants [ʔ] and [*h*] were analyzed separately, because previous research has indicated that the overabundance of glottals only pertains to the glottal stop [ʔ] (Oller, 1991).

A total of 7,879 consonants was analyzed. This included 1,829 consonants for infants with normal hearing, 3,917 for those with mild-to-moderately-severe hearing loss, and 2,133 for those with severe-to-profound hearing loss. The consonants were produced in vocalic context in initial, medial, or final position. An analysis of consonant place for each group showed the following patterns. For infants with normal hearing, consonant place preferences included coronals (39%), labials (35%), glottals (14%), and dorsals (11%). The glottal stop [ʔ] and glottal fricative [*h*] accounted for 3% and 11% of consonant place categories, respectively. For infants with mild-to-moderately-severe hearing loss, consonant place patterns included labials (38%), glottals (30%), coronals (26%), and dorsals (6%). The glottal stop [ʔ] and glottal fricative [*h*] accounted for 20% and 10% of consonant place patterns, respectively. Last, the pattern for infants with severe-to-profound hearing loss was similar to those of infants with mild-to-moderately-severe hearing loss, showing a preponderance of labials (45%), followed by glottals (30%), coronals (22%), and dorsals (2%). The glottal stop [ʔ] and glottal fricative [*h*] accounted for 23% and 7% of consonant place patterns, respectively. Regression analyses were calculated to examine the association of PTA and consonant use in any context. A significant association was found for dorsal consonants, $t(13) = -3.6$, $p = .00$, $R^2 = .51$. No other consonant associations were found to be significant. Figure 1 shows the consonant inventory for each group.

Figure 1. Percentage consonant inventory by place of articulation for infants with estimated PTA of 25 dB HL (normal hearing), better-ear PTA between 37 and 65 dB HL (mild to moderately severe hearing loss), and infants with better-ear PTA greater than 85 dB HL (severe to profound hearing loss).



Discussion

In the present study, we examined prelinguistic vocalization patterns in 15 infants who were identified at birth with varying degrees of hearing sensitivities, ranging from normal hearing to profound hearing loss. The goal was to evaluate the relationship between hearing sensitivity and early vocal patterns in the canonical babbling period. Babbling patterns for infants with normal hearing have been detailed in a number of ways using perceptual analyses, including the CBR, vocalization types within utterances, syllable shapes, number of syllable sequences, and segmental inventories. These aspects of babbling have not been detailed previously in one set of infants with varying degrees of hearing loss who received amplification in the first year of life.

All infants, except 1, were effectively in the canonical babbling stage during the period of study. The variables examined focused on vocalizations related to utterance organization (percentage of utterances containing canonical syllable presence, CBR, and vocalization types in utterances) and to specific characteristics of canonical syllables (i.e., number of sequenced canonical syllables, canonical syllable shape, consonant onset in CV canonical syllables, and segmental inventory of syllables). Hearing sensitivity was associated with the percentage of utterances containing canonical syllables and the types of vocalizations used within utterances. However, hearing sensitivity was not generally associated with canonical syllable characteristics such as syllable shape (except for VCs), syllable sequencing, and onset use, although some trends were observed related to PTA. The results of the present study suggest that even when the sensory and motor criteria that are required to instantiate canonical syllable production in infants with hearing loss are met, some babbling patterns may differ from those observed in infants with normal hearing. This pattern of results suggests that interactive sensory- and production-system variables contribute to the vocalizations observed in the earliest phases of vocalization emergence.

One of the most striking outcomes of this study highlights the extent of the contribution of auditory sensitivity to the production of canonical syllables in utterances, which is considered the hallmark accomplishment of hearing infants during this period of speech acquisition. According to Oller and Eilers (1988), the canonical babbling stage is marked by a CBR of 0.2 or more. Two important findings can be gleaned from Table 3, which shows the CBR and the percentage of utterances containing canonical syllables for each infant in relation to PTA. First, on average, the CBR and the percentage of utterances containing canonical syllable presence in the infants with severe-to-profound hearing loss were lower than those of the infants with normal and mild-to-moderately-severe hearing sensitivity. This pattern is consistent with other studies reporting low CBRs in infants with severe-to-profound hearing loss (e.g., Eilers & Oller, 1994; Koopmans-van Beinum, Clement, & van den Dikkenberg-Pot, 2001; Oller & Eilers, 1988; Stoel-Gammon & Otomo, 1986). Despite early identification–amplification, canonical syllable production in utterances was significantly reduced in the infants with severe-to-profound levels of hearing loss, suggesting that early amplification was not sufficient for triggering the patterns typically observed in infants with normal hearing sensitivity.

Second, the data on CBR and canonical syllable presence in utterances also highlight the high levels of variability observed in the vocalizations produced by infants with hearing loss. For the infants with PTAs greater than 85 dB HL, CBRs and canonical syllable presence data do not seem to follow a predictable linear pattern. That is, for 3 infants (J.H., E.C., and G.W.) with PTAs less than 85 dB HL, CBRs and percentage syllable presence were higher than those observed for the infants with normal hearing. The performance of the remaining infants with PTAs less than 85 dB HL was either equal to or worse than that of infants with normal hearing. Taken together, these findings suggest that severe-to-profound hearing loss exceeding a PTA of 100 dB HL results in low CBRs and low percentage of utterances with canonical syllable presence, whereas hearing loss with PTAs of less than 85 dB HL (and greater than 25 dB HL) can result in variable and unpredictable outcomes.

What factors might have contributed to the variability in the vocalizations observed, particularly for Infants G.W. and J.H. (the 2 most extreme cases)? Were there differences in intervention style, frequency, or signal processing that might have led to differences in the CBR and percentage of utterances containing canonical syllables for these infants? For example, Infant G.W. was the only infant in the severe-to-profound group who wore an individual FM unit at home, during most interactions with the family. Did having access to a home FM system account for G.W.'s high performance relative to the other members of the severe-to-profound group? Because audibility was not confirmed with probe microphone measures, it is unknown how signal audibility might have played a role in shaping this infant's vocalizations. In terms of Infant J.H., it is difficult to speculate as to why he varied so much relative to the other infants in this cohort. J.H. was older than the other members in his group, but he did not have as much hearing-aid experience as other members in his group. Factors such as hearing age, signal audibility, and intervention type and frequency should be controlled in future studies to better determine their effects on vocalization output.

What vocalization types were infants with severe-to-profound hearing loss producing if approximately 72% of their utterance strings did not contain canonical syllables? Results showed that infants with severe-to-profound hearing loss appear to have explored different types of vocalizations, mainly singletons (consonant- and vowel-like sounds) and GSs in contrast to canonical syllables. These results are consistent with previously reported results on infants with this level of impairment, showing a propensity for singleton consonants, vowels, and GSs and use of few canonical syllables (McCaffrey et al., 2000; Oller, 1986; Stoel-Gammon & Otomo, 1986). Variability in vocalization types across infants increased with increasing hearing loss. That is, variability was largest for infants with severe-to-profound hearing loss relative to infants with milder hearing loss and normal hearing. Future studies should examine which factors account for the variability observed. Are these patterns related to the transcription method or does variability increase with increased hearing loss?

Coronal and labial onsets are dominant in the canonical syllables of typically developing infants (Boysson-Bardies & Vihman, 1991; Kent & Bauer, 1985; Vihman et al., 1986). In general, for the infants with mild-to-moderately-severe and severe-to-profound hearing loss, the syllable-onset patterns showed more frequent use of labial than coronal onsets in canonical syllables of CV shape, a reverse pattern from the hearing infants. An increased use of labial consonants (and decrease in use of coronals and dorsals) with increasing PTA was also shown in the analysis of consonant place of articulation appearing in canonical syllables. Both groups of hearing-impaired infants showed the same pattern, suggesting an early reliance on the visual modality rather than on the auditory modality, despite early amplification. In addition, an analysis of glottal consonant use showed an increase in glottal stop [ʔ] use and a decrease in glottal fricative [*h*] use as PTA increased. Previous work on vocalizations of hearing-impaired infants has shown that infants with severe-to-profound hearing loss tend to have a higher occurrence of glottal [ʔ] than hearing infants (Oller, 1991). Oller showed that the highest proportion of glottal sequences appearing in a sample of hearing infants did not exceed 20%, with a mean of 4% to 5%. Results from the present study confirm the patterns previously reported by Oller.

Results from this study indicate that inadequate auditory access to speech results in different speech development patterns than those of hearing infants, even if the hearing loss is mild, suggesting an early codependence of auditory perceptual and speech-production factors in early speech acquisition. Research in infant development suggests that the experience obtained through the coordination of movement–perception systems leads to the further development of action skills. Additionally, perception–action studies have suggested that repetition of active behavior serves as a means to gain and strengthen perceptual knowledge (Thelen & Smith, 1994), termed *embodied cognition* (e.g., Johnson, 1987). Future studies should continue to examine the relationship among audibility factors and the emergence of prelinguistic vocalizations in infants identified early with varying degrees of hearing loss.

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Contact author: Deborah von Hapsburg, who is now at the Department of Audiology and Speech Pathology, University of Tennessee, Knoxville, 548 South Stadium Hall, Knoxville, TN. E-mail: dvh@utk.edu