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Prelinguistic Vocal Development in Infants with Typical Hearing and Infants with Severe-to-Profound Hearing Loss

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Abstract

Delays in the onset of canonical babbling with hearing loss are extensively documented. Relatively little is known about other aspects of prelinguistic vocal development and hearing loss. Eight infants with typical hearing and eight with severe-to-profound hearing loss were matched with regard to a significant vocal development milestone, the onset of canonical babbling, and were examined at three points in time: before, at, and after the onset of canonical babbling. No differences in volubility were noted between the two infant groups. Growth in canonical babbling appeared to be slower for infants with hearing loss than infants with typical hearing. Glottal and glide production was similar in both groups. The results add to a body of information delineating aspects of prelinguistic vocal development that seem to differ or to be similar in infants with hearing loss compared to infants with typical hearing.

Introduction

Hearing loss affects one in every 1,000 children in the United States (National Institutes of Health [NIH] Consensus Statement, 1993). Due to aggressive newborn hearing screening efforts (92% of infants in the United States are presently screened for hearing loss, according to the 2006 Centers for Disease Control and Prevention [CDC] Early Hearing Detection and Intervention [EHDI] hearing screening and follow-up survey), the average age of hearing loss identification in the United States is now considerably lower than 30 months, the age indicated as typical for diagnosis in the 1993 NIH Consensus Statement. Results from a universal newborn hearing screening study indicated that the median age of hearing loss identification was 3 months and for hearing aid fitting was 7.5 months (Dalzell et al., 2000). Programs that target and assess outcomes using prelinguistic vocal skills are, therefore, becoming increasingly crucial. An important first step in the development of these programs and outcome measures will be careful documentation of the course of prelinguistic vocal development in infants with severe-to-profound hearing loss.

Studies of prelinguistic vocal development and hearing loss are also needed because they shed light on the mechanisms of speech and language acquisition. Aspects of vocalizations that are found to be similar in infants with typical hearing (ITH) and infants with hearing loss would suggest that these aspects are robust and perhaps part of our biological heritage, whereas features that are different between ITH and infants with hearing loss would suggest that auditory perception is crucial in the development of these features.

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Delays in the onset of canonical babbling in the presence of deafness (CB), consisting of well-formed syllables such as [ba] or [ni], are well-documented (see Oller, 2000, for a review). Other aspects of prelinguistic vocal development, e.g., volubility, have been the subject of widespread speculations but have not received as much empirical attention. The present study longitudinally investigates several aspects of prelinguistic vocal development in ITH and in infants with severe-to-profound hearing loss (IHL) in order to further characterize the nature of prelinguistic vocal development and to determine whether hearing loss affects this development.

Volubility

Early reports claimed that the number of vocalizations per minute, or *volubility*, of IHL diminishes after 6 months of age (e.g., Lach, Ling, Ling, & Ship, 1970; Lenneberg, Rebelsky, & Nichols, 1965; Maskarinec, Cairns, Butterfield, & Weamer, 1981; Mavilya, 1972). This reduction was presumed to occur due to impoverished auditory input or due to impoverished auditory self-feedback (Fry, 1966; Whetnall & Fry, 1964). However, little empirical evidence was presented in support of the purported low volubility of IHL, and, therefore, the claim can be appropriately characterized as a speculation rather than as a finding.

A few recently conducted empirical observations of volubility and deafness have *not* revealed lower volubility in IHL. Clement (2004) and van den Dikkenberg-Pot, Koopmans-van Beinum, and Clement (1998) found that six IHL vocalized either to the same extent or *more* frequently than six ITH, aged 2.5 to 18 months. Similarly, Moeller et al. (2007) did not note any reliable difference in volubility between ITH and infants with varying degrees of hearing loss at 8.5, 10, and 12 months of age. If these data are representative of the populations of IHL and ITH, then previous beliefs about reduced volubility in IHL may be merely myths.

In addition, data from infants with lesser degrees of hearing loss (e.g., Nathani, Oller, & Neal, 2007; Petinou, Schwartz, Mody, & Gravel, 1999) have not demonstrated differences in volubility with ITH. Similarly, infants with cleft palate produced vocalizations as frequently as ITH at 9 months of age (Chapman, Hardin-Jones, Schulte, & Halter, 2001). Thus, it appears that except for low socioeconomic status (Oller, Eilers, Steffens, Lynch, & Urbano, 1994), volubility may be relatively unaffected by various conditions of risk for speech and language development.

The present study attempts to provide additional data on volubility by matching ITH and IHL on the basis of a vocal developmental milestone rather than of age. The two common ways of matching groups in developmental research are matching by age or by a significant developmental milestone. Volubility and other prelinguistic comparisons for ITH and IHL have not yet been conducted by matching a vocal developmental milestone. The present study will provide one of the first developmental matching comparisons between ITH and IHL.

One source of evidence hints that matching by vocal development might yield volubility differences between ITH and IHL. Ejiri (1998) found that audition is necessary to sustain certain rhythmic behaviors, e.g., rattle shaking. Because CB is also a rhythmic behavior, especially in reduplicated babbling, it is possible that reduction of volubility in IHL might become apparent only *after* the attainment of CB, when audition may play an important role in maintenance of CB. Delays in the onset of CB might also indirectly account for early, speculative claims of reduced volubility after 6 months of age in IHL. Because ITH usually begin CB around the middle of the first year of life, their speech-like vocalization rate may be interpreted as increasing at that point. Assuming that CB has a particularly strong impact on the impressionistic judgment of vocalization rate, IHL who experience delayed onset of CB would appear as if their vocalization rates begin to lag at the point when ITH begin to produce CB. The present study will attempt to evaluate these possibilities by comparing vocal characteristics after matching infants by the onset of CB.

Growth in Canonical Babbling and Other Prelinguistic Syllable Types

The onset of CB has been extensively researched for both ITH and IHL. Findings from this research have shown that deafness can significantly impact the onset of CB. ITH usually begin CB between 5 and 10 months of age, whereas the age of onset for CB in IHL, even with amplification, is usually well beyond 11 months of age (e.g., Eilers & Oller, 1994; Koopmans-van Beinum, Clement, & van den Dikkenberg-Pot, 2001; Oller & Eilers, 1988; Vinter, 1994). Hearing loss also delays the onset of CB even in the case of moderate-to-severe hearing loss, although to a lesser extent than profound hearing loss (Nathani et al., 2007).[1] This delay is viewed as extremely significant because words are composed primarily of canonical syllables, thus it is essentially impossible to develop significant expressive vocabulary without canonical syllable control.

Suggestive, although limited, evidence exists regarding differences in the pattern of CB production after its reported onset in ITH and IHL. ITH sometimes show a sudden onset of CB with stable production thereafter, but many infants show a fairly gradual onset with inconsistent CB during a period lasting at least a month (Lewedag, 1995; Oller, 2000). On the other hand, the production of CB by IHL has been reported to be unstable for a considerable time after the onset of CB, as long as 5 to 6 months after the onset (Steffens, Eilers, Fishman, Oller, & Urbano, 1994; Oller & Eilers, 1988). The overall number of canonical syllables produced by IHL has also been reported as less than that produced by ITH, at comparable ages (Stoel-Gammon, 1988; Steffens et al., 1994; von Hapsburg & Davis, 2006).

Data for IHL on the characteristics of many of the most common *precanonical* (i.e., before the onset of CB) vocalizations reported to occur in ITH are similarly scarce. The available data indicate that some of the most salient precanonical vocalizations are produced in relatively similar ways across ITH and IHL, e.g., raspberries and squeals (Oller, Eilers, Bull, & Carney, 1985; Stoel-Gammon & Otomo, 1986). The development of other prelinguistic vocalization types may, however, be affected by the loss of audition. Lynch, Oller, & Steffens (1989) observed that prior to the emergence of CB, vocal productions of a child were dominated by primitive vowel-like sounds (termed *quasi-resonant nuclei;* definition in “Method” section). Frequent production of other precanonical vocalizations seen in ITH, such as adult-like vowel sounds (termed *fully resonant nuclei;* definition in “Method” section) and primitive consonant-vowel combinations (termed *marginal syllables;* definition in “Method” section), did not occur in the child until after the emergence of CB. Whether the development of quasi-resonant nuclei, fully resonant nuclei, and marginal syllables in infants with less than complete absence of audition is similarly affected is not known. The growth (or lack thereof) of these syllable types after the onset of CB has also not been documented for IHL.

In summary, limited data hint at differences between ITH and IHL in the development of canonical syllables following the onset of CB and in the development of other prelinguistic

[1]It should be noted that more positive outcomes from those reported here have been noted for several aspects of prelinguistic vocal development for infants and toddlers fitted with cochlear implants (e.g., Colletti et al., 2005; Ertmer, Young, & Nathani, 2007; Schauwers, Gillis, Daemers, Beukelaer, & Govaerts, 2004). These outcomes are not discussed here because participants in this study were fitted with hearing and/or tactile aids, but not cochlear implants.

syllable types. The present work will provide additional relevant data on this issue through comparison of ITH and IHL before, at, and after the onset of CB.

Other Aspects of Prelinguistic Vocalizations

Two other aspects of prelinguistic vocalizations—syllable shapes and proportions of true consonants, i.e., consonants other than glides and glottal stops—have received some attention in the research literature. Production of complex syllable shapes and true consonants in typical infant vocalizations is associated with progress toward becoming efficient talkers (Nathani, Ertmer, & Stark, 2006; Vihman & Greenlee, 1987). Delays in the production of these aspects have been associated with poor word production skills (Moeller et al., 2007).

Syllable shapes—In IHL, a limited variety of syllable shapes have been noted. An infant with hearing loss produced restricted syllable shapes, i.e., more open syllables and few closed syllable shapes, when compared to his twin who had typical hearing (Kent, Osberger, Netsell, & Hustedde, 1987). More recent investigations have replicated some of these findings. Clement (2004) included IHL from 2.5 to 18 months of age and noted that IHL produced fewer closed syllables than ITH, but only at 9.5 and 10.5 months of age; few closed syllables were produced overall by either group of infants. Von Hapsburg and Davis (2006) observed that ITH used greater proportions of CV and CVC syllables than IHL, but IHL used greater proportions of VC syllables than ITH (C = consonant; V = vowel). Moeller et al. (2007) reported that children with varying degrees of hearing loss produced less complex syllable structures from 10 to 24 months of age than ITH.

Glottal stops and glides—There have also been reports of reduced production of true consonants and increased production of glottal stops and glides by IHL. Inordinately frequent use of glottal stops (or *glottal sequences)* was observed in multisyllabic utterances of IHL in the first year of life when compared with ITH (Oller et al., 1985; Stark, 1972; Stoel-Gammon, 1988; Stoel-Gammon & Otomo, 1986). Glottal sequences are particularly interesting because they can show clear, well-timed syllabification without any supraglottal articulation, which is a requirement of canonical syllables. Von Hapsburg and Davis (2006) found that whereas an average of 23% of the consonants produced by five IHL at 18 months of age were glottal stops, only 3% of the consonants produced by four ITH at 12 months of age were glottal stops. Similar results for glottal stops were found by Clement (2004). With respect to glides, Stoel-Gammon and Otomo (1986) found greater production of glides by IHL, but these differences in glide production between ITH and IHL were not replicated by Clement (2004).

In summary, the limited empirical data available suggest that complex syllable shapes and true consonants may not be produced as often by IHL and are, therefore, worthy of continued investigation. The present study matched infants on a vocal developmental variable to further delineate the effects of hearing loss on the production of these factors in prelinguistic vocalizations.

Focus of the Present Study

The present longitudinal investigation of vocal development compares eight IHL with eight ITH. In departure from most previous investigations, ITH and IHL were roughly matched on the basis of onset of CB (a vocal developmental variable) rather than age. This exploratory work constitutes one of the first comparisons of prelinguistic vocal characteristics in ITH and IHL based on developmental matching. Although Moeller et al. (2007) also matched ITH and IHL on the basis of CB ratios, they compared only consonant and vowel inventories of ITH and IHL. The present study evaluates several aspects of prelinguistic vocalizations using developmental matching.

Both age matching and developmental matching have interpretive advantages and disadvantages. Children matched on age are expected to be alike in certain maturational ways, which suggests an advantage to age matching to keep general maturation constant while monitoring another variable, such as CB. However, if groups differ on a particularly influential variable (such as hearing), their maturational status can be uneven or globally delayed across various domains. One might also imagine that vocal environments of age-matched children would be similar (again suggesting an advantage to age matching to keep vocal environments constant while monitoring another variable such as CB). But caretakers tend to adjust their input to children at a level of complexity near that of the children's communicative development levels (e.g., Guralnick, Neville, Hammond, & Connor, 2008), suggesting an advantage to developmental matching. Consequently, studies are needed using both kinds of matching and the present work can help fill this gap.

This study examined four aspects of prelinguistic vocal development at three points in time: before the onset of CB (precanonical), at the onset of CB (canonical), and after the onset of CB (postcanonical). These four aspects included volubility; growth in various prelinguistic syllable types, including canonical syllables; production of varied syllable shapes; and glottal stop and glide production. For volubility, the expectation was neutral—the most reliable empirical information to date suggests no volubility reduction in ITH, but there is a long tradition of expectation that volubility should be low in IHL. For growth in prelinguistic syllable types, it was expected that IHL would show slower growth in canonical syllable production across sessions and, thus, show persistence of other prelinguistic syllable types. IHL were also expected to produce a greater number of open syllables and a higher frequency of glottal stops and glides than ITH.

Method

Participants

Eight full-term ITH and eight full-term IHL, matched for socioeconomic status and linguistic background, were longitudinally studied. Gender was balanced in IHL whereas there were seven males and one female in the ITH group.[2] Unaided better-ear pure tone averages for IHL were obtained using behavioral audiometry and revealed severe-to-profound or profound hearing losses for all eight infants. Severe hearing loss was defined by hearing thresholds in the range of 71–90 dB HL, and profound hearing loss was defined by hearing thresholds at 91 dB HL or greater (Goodman, 1965). The average age of identification of hearing loss was approximately 13 months (mean [M] = 12.88; standard deviation [SD] = 7.4), and the average age of amplification was approximately 1.5 months after identification of hearing loss (M = 14.25; SD = 8.4). Six of the eight infants were fitted with both hearing and tactile aids and the two remaining infants were fitted with only hearing aids. These six infants were also enrolled in a total communication program whereas the two remaining infants were enrolled in an oral communication program.

One research paper has been published using this data set (Nathani, Oller, & Cobo-Lewis, 2003). This previous study focused on syllable duration characteristics of ITH and IHL. An expanded description of the participants' demographic characteristics can be found in the previous report.

[2]The gender mismatch was not expected to influence results because gender differences in the qualitative characteristics of prelinguistic vocal development have not been demonstrated in any previous work (e.g., Lynch, Oller, Steffens, & Buder, 1995; Camp, Burgess, Morgan, & Zerbe, 1987).

Recording Environment and Procedures

Vocalizations of ITH were recorded in the company of either a parent, a staff member of the research project, or both. The parents and staff were encouraged to promote the production of vocalizations as much as possible during the recording sessions. Vocalizations of six IHL were recorded as they interacted with a speech-language pathologist during therapy sessions. The speech-language pathologist also attempted to promote vocalizations during the recording sessions. Vocalizations from the remaining two IHL were recorded under the same conditions and procedures as ITH.

Criteria for Selection of Sessions

A precanonical, a canonical, and a postcanonical session were selected for each infant. The first session was the canonical session, chosen based on the onset of CB. For ITH, CB ratios (the number of canonical syllables divided by the number of utterances) of 0.2, as determined by prior codings (Oller et al., 1994), were used to select the canonical sessions. For IHL, the canonical sessions were not referenced to prior codings because these were not available. Instead, the first recording for six IHL available after the reported onset of CB by teachers or speech-language pathologists, who had closely worked with these infants, was designated the canonical session. The teachers and speech-language pathologists had been trained to identify the onset of CB by the second author of this manuscript. For the remaining two IHL (not in the same clinical program), the canonical sessions were the first recording session after the onset of CB as reported by the parents. Identification of the onset of CB by adults who have considerable contact with an infant has been shown to be remarkably reliable (Oller, Eilers, & Basinger, 2001).

For both groups, a session that was recorded approximately 3 months before the canonical session was designated the *precanonical* session, and a session that was recorded approximately 3 months after the canonical session was designated the *postcanonical* session. Ages corresponding to the precanonical, canonical, and postcanonical sessions for ITH were approximately 4 (SD = 1.1), 7 (SD = 0.79) and 10 (SD = 1.2) months; and for IHL were approximately 24 (SD = 11.04), 27 (SD = 11.13) and 30 (SD = 11.24) months, respectively.

Data Coding

Identification of utterances and syllables—Only vocalizations that were considered precursors to meaningful speech were categorized as utterances. These precursor vocalizations, termed protophones in the infraphonological model of vocal development and previously referred to as nonvegetative vocalizations, include vocalization types such as those traditionally called cooing and babbling. Vocalization types that have obvious biological functions (e.g., hiccup, sneeze) or obvious social functions (e.g., cry, laugh) were not categorized as utterances because they are presumed to have only indirect linkages to speech (Oller, 2000).

Utterances were generally defined as a vocalization or group of vocalizations separated from all others by either audible ingressive breaths or by the primary judge's intuitions about utterance boundaries, which are often indicated by a silence of 1 second or longer (Lynch et al., 1989; Stark, 1980). A second judge coded a randomly selected subset of vocalizations (10% from each infant group) to provide reliable data on the utterance determination by the primary reseacher. The two judges agreed on the occurrence of utterances 86% of the time. Cohen's kappa for utterance agreements was 0.66 (Cohen, 1960, 1968). Kappa values of 0.60–0.75 have been characterized as showing *good* agreement and those greater than 0.75 as showing *excellent* agreement (Fleiss, 1981).

Because analysis of a small number of utterances can result in underestimation of the developmental status of prelinguistic vocalizations (Kent & Miolo, 1995), sessions had to contain at least 50 utterances. In cases where sessions yielded fewer than 50 utterances, additional recordings within a month of the session of interest, if available, were aggregated to yield 50 utterances (Wachs, 1991). Even after this aggregation, data analyzed for three sessions (two for IHL and one for ITH) contained fewer than 50 utterances (22, 30, and 48 utterances, respectively).

The number of syllables within these utterances was then determined using the construct of countable *beats* (Nathani & Oller, 2001). The primary judge counted the number of beats they heard in each utterance to determine the number of syllables that would be coded for protophone types. A second judge coded a randomly selected subset of utterances (10% from each infant group) in order to verify the syllable counts of the primary judge. Cohen's kappa for interjudge agreement for syllable counts of all infants was 0.7.

Determination of canonical babbling and other prelinguistic syllable types— Judges assigned syllables to one of five syllable types: canonical syllables, marginal syllables, fully resonant nuclei, quasi-resonant nuclei, and other, as recommended by the infraphonological model of prelinguistic vocal development (Oller, 1980, 2000). *Canonical syllables* refer to consonant-vowel-like combinations with rapid (nominally <120 ms) adult-like transitions between the consonant and vowel. It is important to add that the definition of canonical syllable does not rule out VC shapes. Syllables such as [at] or [em], if well articulated according to the principles indicated above, are treated as canonical. *Marginal syllables* are similar to canonical syllables except that they are perceived to have slow transitions between closures and openings of the vocal tract (typically exceeding 120 ms, a fact that can often be verified by spectrographic inspection of formant and amplitude [RMS] changes), and often sound "sloppy" or "slurred."

Quasi-resonant and *fully resonant* nuclei designate vowel-like sounds that are produced without any adjacent consonantal elements. The distinction between fully resonant and quasi-resonant nuclei is based on whether the vowel-like sounds are perceived as having been produced with an open (fully resonant) or an at-rest (quasi-resonant) position of the supraglottal vocal tract. Because quasi-resonant nuclei are produced during an at-rest position, they are considered more primitive and less speech-like than fully resonant nuclei. *Other* refers to those protophones, e.g., raspberries, which cannot be coded using any of the four primary categories. The syllable types were coded using the Logical International Phonetics Programs (LIPP) (Oller, 1991).

An additional judge coded a randomly selected subset of vocal samples (10% from each infant group) in order to establish reliability for the primary judge's codes. Cohen's kappa for infraphonological coding of syllable types was 0.72.

Determination of syllable shape—Syllable shapes were classified as *open* or *closed* by the primary judge. Open syllable shapes contained a vowel-like element at the syllable offset, e.g., CV, whereas closed syllable shapes had a consonant-like element at the offset, e.g., VC. Only fully resonant nuclei and canonical syllables were included in this analysis because they bear the greatest resemblance to mature speech. All vocalizations classified as fully resonant nuclei were automatically classified as open syllables because each such vocalization consists of a vowel-like element alone. A second judge confirmed or rejected all the syllable shape determinations of the primary researcher. Only consensus agreements were used for these analyses.

Determination of glottal stops and glides—The occurrence of glottal stops and glides was noted. Consensus agreements, as described for syllable shapes, were used in the analysis.

Results

Volubility

The rate of utterance and syllable production, i.e., numbers of utterances and syllables per minute, were computed for each session to measure volubility. Table 1 shows syllables and utterances per minute, respectively, produced by ITH and IHL across the three sessions. There was considerable inter-infant variability in the volubility data. Volubility values (in syllables per minute) ranged from 2.38 to 22.08 for ITH, and 1.13 to 43.44 for IHL. There was also considerable intersession variability. Volubility values for one ITH across sessions ranged from 3.27 to 15.66, and for one IHL from 0.67 to 16.66.

A repeated measures mixed-model analysis of variance[3] was used to analyze the data for all dependent measures. The between-subjects variable was group (ITH, IHL) and the within-subjects variable was session (precanonical, canonical, and postcanonical). No main effect of group, session, or interaction was significant for syllables or utterances per minute. Thus, these results did not indicate statistically significant differences in volubility between the two groups or across sessions.

Although the differences were not statistically reliable, it is interesting that the trends were predominantly opposite of the traditional expectations of low volubility in IHL. First, volubility, as measured by utterances per minute, showed reduction across sessions for ITH but not for IHL. The traditional expectation was that IHL would show reduction in volubility across time, and ITH would show an increase. Similarly, contradicting the traditional expectation, the rate of utterance production was higher for ITH than for IHL only in precanonical sessions. That difference appeared to turn in favor of IHL in the later sessions.

Growth in Canonical Babbling and Other Prelinguistic Syllable Types

Syllable-type ratios were calculated by dividing the numbers of individual syllable types by the total number of syllables. For example, the CB ratio was the number of canonical syllables divided by the total number of syllables. Figures 1 and 2 show the mean proportions (and standard errors) of the four main syllable types across the three sessions for the two groups, ITH and IHL, respectively. Other syllable types occurred rarely for both groups: average of 2% and 6% for ITH and IHL, respectively.

Canonical babbling—Figure 1 shows that CB ratios were higher in canonical than in precanonical sessions for ITH. The CB values went up further in the postcanonical sessions. Figure 2 shows a different picture for IHL. First, there was greater inter-infant variability during all sessions than that for ITH. Second, although there was a slight increase in production of CB from the precanonical to canonical session, CB appeared to reach substantial proportions only in postcanonical sessions.

Statistical analysis revealed that there was a significant Group*Session interaction—$F(2, 27) = 4.85$, $p < 0.05$, $\omega^2 = 0.199$—indicating different developmental trajectories in the two groups. It should be noted that because different numbers of utterances were produced in different sessions, data were weighed differentially according to the number of utterances

[3]Because of small sample sizes in the present study, statistical power to detect differences was limited. Statistical analyses were, therefore, applied throughout the study with caution and results are intended to be viewed as exploratory in nature.

(Verbeke & Molenberghs, 2000). Post hoc contrast tests using Tukey-adjusted p values revealed that CB significantly increased across the three sessions for ITH. CB ratios produced by ITH in canonical sessions were significantly greater than those produced by IHL in precanonical sessions. At the same time, CB produced by ITH in postcanonical sessions also occurred at significantly higher proportions than those produced by IHL in both precanonical and canonical sessions. IHL did not significantly increase their production of CB across the three sessions.

One infant in the IHL group appeared to be an outlier because she had a 0.43 proportion of CB in her precanonical session; average of CB ratios across all other infants in the precanonical session was only 0.01. When the data were reanalyzed without this infant's data, overall significance effects were identical to those based on the entire data set. There were, however, differences in the post hoc focus tests conducted using Tukey-adjusted values. ITH produced significantly more canonical syllables than IHL in canonical sessions when this infant was excluded, whereas this difference was not significant for the original data set.

A more important and reliable contrast that did not change even with removal of the outlying infant's data was that IHL did not significantly produce more canonical syllables in postcanonical sessions than in precanonical sessions, while ITH showed a statistically reliable change in CB ratio from precanonical to postcanonical. Thus, the presence of this outlier did not affect the statistical reliability of differences in CB ratios for IHL between precanonical and postcanonical sessions despite her relatively stable, high CB ratios across all three sessions. The key point, consistent with prior claims of the literature, was that ITH appeared to show more rapid progress in their command of canonical syllables than IHL.

Marginal syllables—Marginal syllables were not frequently produced by either group. They occurred at a rate between 0.1 and 0.2 in all sessions for ITH (Figure 1) and lower than 0.2 in all sessions for IHL (Figure 2). No statistically significant effects were obtained for marginal syllables.

Quasi-resonant nuclei—Figure 1 shows that for ITH, the proportions of quasi-resonant nuclei sharply decreased in the canonical sessions and continued to decrease in postcanonical sessions. Quasi-resonant nuclei steadily decreased for IHL across the three sessions, with a ratio of less than 0.15 for the postcanonical sessions. Statistical analysis showed that Session had a significant effect on quasi-resonant nuclei for both ITH and IHL, $F(2, 27) = 4.72$, $p < 0.05$, $\omega^2 = 0.194$. Post hoc focus tests using Tukey-adjusted p values revealed that quasi-resonant nuclei were significantly lower in postcanonical sessions ($M = 0.1$, $SD = 0.09$) than in precanonical sessions ($M = 0.26$, $SD = 0.19$). No main effect of group or interaction effect was significant.

Fully resonant nuclei—Fully resonant nuclei were the most frequently occurring syllable type in precanonical and canonical sessions for ITH (Figure 1); canonical syllables were the most frequent syllable type in the postcanonical sessions. In contrast, fully resonant nuclei were the predominant protophone type across *all* three sessions for IHL, accounting for approximately half the syllables (Figure 2).

The interaction effect of Group*Session for fully resonant nuclei narrowly missed the 0.05 significance criterion, $F(2, 27) = 3.15$, $p = 0.0591$, $\omega^2 = 0.122$. Post hoc contrast tests using Tukey-adjusted p values did not reveal any significant differences. The main effect of either group or session was not significant. Thus, hearing status or level of vocal development did not strongly influence the production of fully resonant nuclei in most regards. However, the tendency of ITH toward a reduced rate of fully resonant nuclei production in comparison with CB production in the postcanonical session may deserve further attention.

Other Aspects of Prelinguistic Vocal Development

Syllable shapes—Neither group produced many closed syllable shapes. Even in postcanonical sessions, ITH had a median of 2% closed syllables and IHL had a median of 3%. Thus, only open syllables were considered for further analysis. The shift to open syllables left just two types for analysis, CV and V (fully resonant nuclei). Entropy analysis for open syllables revealed a significant interaction effect for Group*Session, $F(1.8, 25.7) = 4.08$, $p < 0.05$, indicating a different developmental trajectory for the two groups. ITH significantly produced CV shapes in canonical and postcanonical sessions, whereas IHL did not significantly produce CV shapes until the postcanonical sessions. Thus, the results support the view that IHL show less focus on basic canonical syllables (the CV syllable) than ITH. For both canonical syllables in general (as reported in the previous section), and for canonical syllables of the shape CV in particular, IHL showed slower growth than ITH.

Glottal stops and glides—Table 2 provides data for glottal stops and glide production by the two groups across the three sessions. Overall, the proportion of glottal stops reduced from precanonical to postcanonical sessions for both groups. There was also substantial individual variability within the IHL group, especially in the precanonical sessions. Even though glottal production showed a tendency to be higher at all three stages in IHL than in ITH, no significant main effect for group or session, or interaction effect was revealed.

Glides were rarely produced by either infant group. The only statistically significant effect was the main effect for Session, $F(2, 42) = 4.43$, $p < 0.05$. Post hoc contrast tests indicated that the number of glides were significantly lower in precanonical sessions ($M = 0.02$, $SD = 0.03$) when compared to canonical sessions ($M = 0.03$, $SD = 0.05$) for both infant groups. No significant difference in glide production between canonical and postcanonical sessions was noted.

Discussion

The present study sought to obtain data on relatively little-explored aspects of prelinguistic vocalizations through comparisons of IHL and ITH, matched on the basis of vocal development. Results addressed specific hypotheses regarding similarities and differences between IHL and ITL for volubility, CB, and other prelinguistic syllable types, syllable shapes, and glottal and glide production.

Volubility

In this study, a negative finding would be of most significance. Indeed, results indicated similar frequency of vocalizations in ITH and IHL. Thus, contrary to speculation by early researchers (e.g., Teervoort, 1962; Fry, 1966; Mowrer, 1960), volubility was not lower in IHL than ITH for syllables or utterances. The present results are in concordance with Clement (2004), Moeller et al. (2007), and van den Dikkenberg-Pot et al. (1998), who noted similar volubility in IHL and ITH. Furthermore, the present study provided data that refutes prior speculations (e.g., Lenneberg et al., 1965) that ITH would surpass IHL in volubility after the onset of CB. Results did not indicate reliable differences in volubility between the two groups before, at, or after the onset of CB.

One of the key early claims (a speculation unsupported empirically) was that volubility in IHL tended to decrease across development. In fact, the present work indicates that the reduction in utterances per minute from the precanonical to the canonical session was more notable for ITH than for IHL. Because the rate of *syllable* production in ITH did not correspondingly decrease with the onset of CB, the likely explanation for a reduction in rate of utterance production with the onset of CB in ITH is that more syllables were produced per utterance in canonical sessions than in precanonical sessions. Because utterances, as defined here, roughly correspond to "breath groups," it may be that when ITH start producing canonical syllables they also produce longer strings of syllables within a breath group (or utterance) than before, perhaps as a result of increasing respiratory control. The common occurrence of reduplicated and variegated babbling, i.e., strings of canonical syllables, at the onset of CB in ITH appears to support this possibility (Oiler, 1980Oiler, 2000; Smith, Brown-Sweeney, & Stoel-Gammon, 1989). Because IHL were considerably older and, therefore, physiologically more mature than ITH, even in precanonical sessions a corresponding increase in syllables per utterance would not necessarily be expected with the advent of canonical syllable production for IHL, and indeed none appeared to occur. Still, the changes in rate of syllable and utterance production were not statistically reliable for either IHL or ITH in the present study, and their interpretation is therefore speculative.

The interpretation of the lack of significant volubility differences between IHL and ITH should be tempered by the limited sample size. Type II error is obviously a possibility, i.e., the error of failing to reject the null hypothesis when, in fact, the alternative hypothesis is true, but it should be remembered that several studies (all with small samples) have now failed to find low volubility in DHL. Of course, the circumstances of developmental matching are inherently different from those of age matching, and those circumstances should be considered in interpretation. Notably, empirical investigations with both styles of matching have thus far failed to find a difference in volubility between IHL and ITH.

An additional caveat is that IHL were fitted with appropriate amplification and enrolled in extensive intervention programs and this may have positively influenced volubility in IHL. Finally, the circumstances of recording should be kept in mind. In the present work, six IHL, who were enrolled in early intervention programs, were recorded as they interacted with a speech-language pathologist, whereas ITH were recorded as they interacted with their parents. The two youngest IHL were recorded with their parents in a manner similar to that used with ITH. In all cases, the circumstance of recording interaction was designed to maximize vocalization from the infants. Given the developmental matching procedure, we deemed it reasonable to use an elicitation procedure with each group and adapted the procedure to the age and social abilities of the child. Still, in future work it might be instructive to compare elicitation results for vocalization by parents and speech-language pathologists. It is conceivable that parents would be either better or poorer at eliciting vocalizations from either IHL or ITH, but to our knowledge this topic has never been empirically addressed. In addition, it may be useful to evaluate whether similar results for volubility are obtained under more naturalistic circumstances, e.g., in free play.

In summary, the findings from the present study add to a growing body of evidence that volubility may be a fairly robust maturational phenomenon in infancy. Little (if any) variation in volubility appears to exist across groups of infants as a result of important handicapping conditions.

Growth in Canonical Babbling and Other Prelinguistic Syllable Types

With respect to individual syllable types, the groups showed some similarities and some differences. Both ITH and IHL showed reduced production of quasi-resonant nuclei across sessions. Once CB reached 0.15,[4] quasi-resonant nuclei were rarely produced by either group. Thus, it appears that primitive vowel-like productions diminished with the onset of CB for both ITH and IHL. Similarly, the production of marginal syllables was not reliably different between the two groups. Thus, unlike the child studied by Lynch et al. (1989), IHL behave similarly to ITH in the production of these precanonical syllable types.

On the other hand, although the findings are not statistically significant, fully resonant nuclei appear to diminish across sessions for ITH but not for IHL. Continued predominance of vowel-like elements even after the onset of CB in IHL has also been noted by Koopmans-van Beinum et al. (2001). The results suggest that growth in syllables containing both consonant-like and vowel-like elements does not occur in IHL as rapidly as in ITH, a pattern that may lead to a persistence of syllables containing vowel-like elements alone.

Other investigations, e.g., Kent and Bauer (1985) and Nathani et al. (2006), observed that vowels in their studies were predominant in ITH until 16 to 20 months of age, while in the present study canonical syllables outnumbered vowels by 10 months of age (although only by a small amount). This apparent age difference across the studies is hard to interpret. Only the present study reported data with respect to the onset of CB, and only the present study was longitudinal. It is also possible that the ITH in the present study were more advanced in vocal development than those in the prior studies because the ITH in the present study were fully canonical by 7 months old, whereas the ITH in the Nathani et al. (2006) study had not reached a fully canonical stage until 9 months old. The present results cannot be generalized to indicate with any precision when canonical syllables become the predominant vocal types in ITH. The point that seems more reliable, based on the present study and the others cited, is simply that canonical syllable production increases with age and eventually overtakes full vowel production in ITH. The present results further suggest that this may happen faster in ITH than in IHL.

To illustrate this point further, consider canonical syllable production. Whereas ITH achieved CB ratios of 0.25 and 0.41 on average in canonical and postcanonical sessions (SD = 0.11 and 0.24, respectively), IHL achieved CB ratios of 0.11 and 0.25 in the same sessions (SD = 0.15 and 0.23, respectively). Thus, it appears that IHL consolidate the production of canonical syllables more slowly than ITH. This result was statistically reliable even with the exclusion of the outlier infant in the IHL group. In the absence of audition, the onset of CB does not appear to guarantee timely continued development of canonical syllable production.

This conclusion is tentative because it is possible that differences in the session selection process for the two groups could have resulted in the canonical sessions for ITH being biased toward higher CB ratios than the sessions sampled for IHL. For ITH, these sessions were specifically selected because prior codings had suggested these infants exceeded the CB ratio criterion in the samples. For IHL, the sessions had been selected to occur after the onset of the canonical stage as designated by teacher/parent report, but were not specifically selected to have criterion-level CB ratios. Although it would have been ideal to select sessions for IHL on criterion CB ratios as well, these ratios were not available for this group.

The data can be broken down an additional way to help gain perspective on why we are inclined to take seriously the fact that IHL showed slower growth of CB from canonical to postcanonical sessions than ITH. First, recall that the data were all recoded for the present

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[4]The present study used the criterion of 0.15 CB ratio as an indicator of the onset of CB. This criterion differs from that reported in the first papers on CB from the Miami project because the denominator in those studies was not syllables, but utterances and, consequently, the value of the CB ratio could sometimes exceed 1 (e.g. Oiler et al., 1985). With the syllables denominator, as adopted by the Miami group in later work, the CB value could range precisely from 0 to 1 (Lynch et al., 1989). For this calculation procedure, the criterion ratio for onset of CB was, therefore, lowered to 0.15 rather than the prior value of 0.2. Although the prior 0.2 criterion and utterances denominator had been used in session selection of ITH samples for the present study, all the data were recoded and reinterpreted here, so there was no need to maintain the old procedure.

study and that only *some* of the samples in both groups actually met or exceeded the 0.15 CB ratio criterion designated as "canonical." Six ITH and three IHL met or exceeded the CB ratio criterion in the designated canonical sample, while two ITH and five IHL failed to reach the criterion. The average postcanonical CB ratio was higher for the ITH than the IHL in both cases: 0.44 to 0.38 for those who met the canonical criterion in the designated canonical sample, and 0.33 to 0.23 for those who did not meet the criterion. Perhaps more important, a comparison of the amount of increase in CB ratio from the canonical to postcanonical session showed an average of 0.14 for the six ITH who had met the criterion at the canonical stage, but only an average increase of 0.02 for the three IHL who met the criterion.

It is also notable that only four of the eight IHL achieved 0.15 CB ratios in their postcanonical sessions, while seven of the eight ITH achieved the criterion. Prior evaluation of the stability of CB in laboratory samples after the date of designated onset of CB suggests that ITH indeed do sometimes fail to meet the criterion, quite often in the first month after the designated onset (about 50% of samples), but much less often at 3 months after onset (less than 15% of samples). The results are thus consistent with the expectation that ITH show more consistent growth of CB than IHL once the canonical stage is underway. Still, research with larger sample sizes is necessary to confirm this apparent tendency.

Other Aspects of Prelinguistic Vocal Development

Two additional aspects explored in the present study—production of varied syllable shapes and production of glottal stops and glides—showed similarities and differences between the two infant groups.

Syllable shape—Both ITH and IHL predominantly produced open syllable shapes. Nathani et al. (2006) reported that closed syllable shapes emerged in English-learning ITH only at 16–20 months of age. Similarly, Vihman (1993) noted that ITH who were learning English produced closed syllables in significant quantities only after acquiring a 25-word vocabulary. Given that both ITH and IHL were prelinguistic in the current investigation, the absence of a substantial proportion of closed syllables is not surprising. It may be that open syllable shapes are part of our biological heritage (Jakobson, 1968, originally published 1941), perhaps due to the stronger acoustic cues for initial, as opposed to final, consonants (for a review, see Stevens, 2002). Closed syllable shapes might require considerable exposure to an ambient linguistic environment that includes final consonants before they become prominent. See von Hapsburg and Davis (2006), however, for contrasting results.

Glottal stops and glides—Overall, the present data show a weak and not statistically reliable tendency toward more frequent production of glottal stops by the IHL and a reduction in glottal stop production across sessions for both infant groups (see Table 2). This finding appears surprising, given previous reports of considerable differences in glottal stop production between ITH and IHL (e.g., Kent et al., 1987;Oiler et al, 1985). It may be that the small sample size, variability within infant groups, and the low proportion of glottal stops, in general, might have precluded finding reliable group differences in glottal stop production. Another reasonable possibility to consider is that glottal stops may have been rarely produced by IHL because they were considerably older than those studied in previous investigations. The reports of high usage of glottal sequences in IHL have pertained to younger infants. This point is underscored by the observation that the highest proportion of glottal stops (0.47) in the present study occurred in the precanonical session of the youngest IHL in a sample at 8 months of age.

No differences in groups on glide production were noted. Again, small sample size, variability, and overall low proportions of glides might have obscured group differences in glide production. These findings are in accord with recent data from Clement (2004) that did not reveal reliable differences in glide production between the two infant groups when they were matched for age. The present data extends those findings to suggest that even when matched for vocal development, increased production of glides by IHL was not observed, at least at prelinguistic levels of vocal development. Thus, no differences were found in the proportions of vocalizations that contained true consonants between ITH and older, but matched for vocal development, IHL.

Conclusion

Controlling for the onset of CB between infant groups with and without hearing loss provides both confirmations of some prior reported patterns of vocal development and lack of confirmation of others. Results provided no indication of low volubility in IHL compared to ITH, a finding that adds to growing empirical evidence that casts serious doubt on the widespread belief that hearing loss is accompanied by low volubility. On the other hand, IHL, after the onset of CB, did not consolidate and stabilize their production of CB as quickly as ITH, a pattern that has previously been reported but for which empirical support has been tentative. Fully resonant nuclei instead appeared to persist in IHL even in postcanonical sessions, unlike ITH. This pattern is potentially very important because canonical syllables are the foundation for the vast majority of words in natural languages—without them no one can truly command a spoken language.

Production of quasi-resonant nuclei and marginal syllables were comparable between the two groups, a pattern that tends to confirm reports that the most frequently occurring *precanonical* sounds in infants tend to be similar in ITH and IHL, and that the pattern holds when the groups are matched for development. Glide and glottal production did not vary between the two groups. The lack of difference between IHL and ITH on glottal sequences may have been influenced by the advanced age of the IHL in this study, and it will be important in the future to further evaluate the possibility that excessive production of glottal sequences in IHL is restricted to younger ages.

Taken together, these results suggest that early interventionists working with infants with hearing loss might want to focus their intervention goals to a greater extent on enhancing the quality of prelinguistic vocalizations, especially canonical syllables. Of course, volubility and other aspects of prelinguistic vocalization should continue to be closely monitored in IHL and, if any deficits are noted, they should be addressed. However, findings from this study indicate that canonical syllables are especially vulnerable to hearing loss, and early interventionists should continue to promote the production of these syllables well beyond the initial emergence in order to ensure the consolidation of canonical syllable production.

Although the present study provides the first general comparison of early vocal development in IHL and ITH with developmental matching, it would be even more useful if future studies could match infants by both age and level of vocal development—this would require a three- or four-group study. Recent initiatives on early detection of hearing loss via universal newborn hearing screening should greatly assist in this process because new longitudinal data on IHL in the first year of life should be easier to acquire now than in the past.

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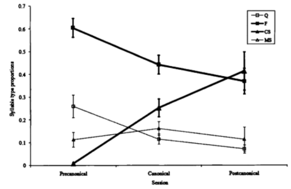

Figure 1.
Mean proportions (and standard errors) of quasi-resonant nuclei (Q), fully resonant nuclei (F), marginal syllables (MS), and canonical syllables (CS) across sessions for ITH.

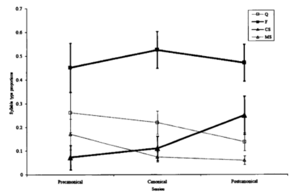

Figure 2.
Mean proportions (and standard errors) of quasi-resonant nuclei (Q), fully resonant nuclei (F), marginal syllables (MS), and canonical syllables (CS) across sessions for IHL.

Table I

Average number (and standard error) of syllables and utterances per minute across three sessions for ITH and IHL

Group and Session	Syllables per Minute	Utterances per Minute
ITH		
Precanonical	10.83 (2.32)	8.16 (2.21)
Canonical	7.78 (0.96)	4.47 (0.54)
Postcanonical	7.56 (2.02)	4.64 (1.07)
IHL		
Precanonical	10.47 (4.99)	5.41 (2.03)
Canonical	8.93 (2.57)	5.82 (1.63)
Postcanonical	8.91 (1.94)	5.09 (0.87)

Table 2

Average proportion (and standard error) of syllables containing glottal stops and glides across three sessions for ITH and IHL

Group and Session	Glottal Stops	Glides
ITH		
Precanonical	0.07 (0.02)	0.01 (0.004)
Canonical	0.04 (0.01)	0.06 (0.02)
Postcanonical	0.03 (0.01)	0.04 (0.01)
IHL		
Precanonical	0.11 (0.06)	0.03 (0.01)
Canonical	0.05 (0.02)	0.04 (0.01)
Postcanonical	0.06 (0.01)	0.02 (0.01)