THE RELATIONSHIP BETWEEN LARYNGEAL CONSTRICTION AND VOWEL QUALITY IN INFANTS LEARNING ENGLISH AND BAI

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ABSTRACT

This exploratory acoustic study focused on the relationship between laryngeal constriction and vowel quality in the vocalizations of infants aged 0-12 months learning Bai, which employs laryngeal constriction distinctively in its register tone system, and English, which uses laryngeal constriction only paralinguistically. Spectral tilt (H2-H1) measurements of front, neutral, and open vowels showed that for both groups, front vowels were least, and open vowels most, likely to be constricted, with neutral vowels falling in between. However, across vowel categories, Bai infants' vowels were significantly more constricted than English infants', suggesting the influence of the ambient language. Moreover, preliminary analysis of open vowels from months 1 through 12 suggests that English infants adopt a vocal setting that favours a lesser degree of constriction early in the first year of life, while Bai infants retain a vocal setting that results in a greater degree of constriction throughout the first year.

Keywords: laryngeal phonetics, first language acquisition, infant vocalizations, spectral tilt

1. INTRODUCTION

Studies of infant physiology, e.g. [3, 8] show that infant and adult vocal tracts differ in several respects. For example, the tongue is in a retracted position; the vocal folds are short and the muscles that control them are undeveloped; and, compared to adults, the larynx is in a higher and more constricted position. Overall, the configuration of the infant vocal tract favours the production of laryngeally constricted sounds in infancy, although infants do begin to have some control over laryngeal parameters early in the first year. Starting in the third month of life, the infant vocal tract undergoes significant growth and restructuring. The larynx, epiglottis, and hyoid bone begin to descend, lengthening the vocal tract and changing the angle of the oral cavity relative to the pharyngeal cavity. This restructuring continues throughout infancy, affording infants the capacity to produce a wide range of pitch, intensity, and constriction at the laryngeal level.

While few phonetic studies have focused on the development of laryngeal constriction in infancy, existing research, e.g. [1, 2], suggests that infants from diverse language backgrounds produce primarily constricted sounds in the first months of life, but produce an increasing proportion of unconstricted sounds over the first year of life. These studies, e.g. [1], have also found that if the ambient language employs laryngeal constriction distinctively, the decline of laryngeal constriction may not be as steep as it is among infants whose ambient language does not use constriction for linguistic purposes. However, these studies have relied exclusively on auditory judgments of constriction; have not analyzed degrees of constriction in infant vocalizations; and have provided mostly a general overview of how laryngeal constriction develops in infant vocalizations. More nuanced studies of laryngeal constriction in infancy are necessary.

Esling's model of the vocal tract, which is based on extensive laryngoscopic observations [5, 7], suggests that laryngeal settings influence vowel quality. An unconstricted laryngeal setting correlates with vowels that are more fronted and raised, along with unconstricted phonation types, such as breathy and modal voice. By contrast, a more constricted laryngeal setting produces vowels that are more retracted, along with constricted phonation types that range from raised larynx voice to harsh voice with aryepiglottic trilling [6].

This exploratory study is the first step in a larger study that will focus on the relationship between laryngeal constriction and vowel quality in the vocalizations of infants learning Bai and English. Bai (Tibeto-Burman) is a register tone language with eight contrasting tone/vocal registers, three of which are unconstricted (two modal; one breathy), and five of which are constricted [7]. By contrast, English (Germanic) employs laryngeal constriction only for paralinguistic purposes (e.g., for expression

of emotion or attitude). If there is a systematic relationship between vowel quality and laryngeal constriction, then we hypothesize that early in infancy, infants from both language groups are most likely to produce vowels that involve laryngeal constriction, such as [ɑ], which is produced with tongue retraction; and least likely to produce vowels that are less susceptible to laryngeal constriction, such as [i], which is produced with tongue advancement. Second, the degree of constriction with which vowels are produced is likely to vary as infants' vocal physiology changes, affording them greater control over laryngeal constriction and a lesser inherent predisposition to produce it. Third, Bai infants are more likely than English infants to produce vowels with a laryngeally constricted setting throughout infancy. Finally, while the influence of the ambient language may be evident in all infant vocalizations, the effect of the ambient language is most likely to be seen in infant babbling. While our research program aims to address all four hypotheses, this paper addresses only the second and third hypotheses above.

2. METHODOLOGY

2.1. Subjects

Five infants (3 female, 2 male) from English-speaking families living in Canada and four infants (2 female, 2 male) from Bai-speaking families in China were recorded in their home environment. While not all infants were recorded each month, the data presented in this paper include a recorded session of at least two infants per month from 1 to 12 months.

2.2. Recording procedure

A digital camera with integrated microphone was used to film the infants interacting with their caregivers in their home environment. The camera was directed at the infant and held at a reasonable distance so as to not distract the infant from the caregiver while ensuring proper capture of the sounds produced by the infants.

2.3. Analyses and categorization

All non-babbled sounds produced by the 9 infants during the first 20 minutes of the recording sessions were used for the analysis, including sounds that have been labeled as cooing, grunting, coughing, or squealing in previous research. A non-babbled sound was defined as a vocalic sound; or, more specifically, one that was not produced in the context of a CV syllable with an oral consonant. Sounds that could not be judged accurately (e.g. because of background noise) were excluded from analysis.

The data were organized into four age groups: 0-3 months, 4-6 months, 7-9 months, and 10-12 months. In the first part of the study, which focused on months 10-12, 300 tokens of each of front, neutral, and open vowels were identified for each language group by a trained phonetician. (Vowels that were produced with extreme constriction—those exhibiting diplophonia and/or noticeably aperiodic voicing—were excluded from analysis, because they would be difficult to analyze employing the measure of spectral tilt adopted in this study.) From this database, 50 tokens were randomly selected for each vowel category for further analysis. While vowels were not specifically labeled for this study, front vowels included those that were auditorily perceived to be [i], [ɪ], [e], and [ɛ]. Neutral vowels included [ə], [ɚ], [ɜ] and [ɐ]. Open vowels included [a], [ɑ], and [æ]. This process resulted in a total of 150 vowels for each language group, or 300 in all.

The second part of the study focused on months 0-3, 4-6, 7-9, and 10-12. For this study, open vowels were the focus of the analysis. Fifty tokens were selected for each language group for each age category. (The open vowels selected for the first part of the study were used for months 10-12.) A total of 400 vowels were analyzed, 50 for each age category and language.

For both parts of the study, spectral tilt measurements were taken from the central part of each vowel, during a portion where pitch was judged to be relatively stable. H2-H1, calculated by subtracting the amplitude of the first harmonic from the amplitude of the second harmonic, was selected as a measure of spectral tilt. This measure is considered to provide a reliable indication of glottal tension [4], distinguishing between constricted settings such as harsh and creaky voice, which are associated with high spectral tilt values; and unconstricted voice qualities such as modal and breathy voice, which are associated with low spectral tilt values, reflecting the different ratios of open and closed quotients in the glottal waveforms of constricted versus unconstricted utterances.

3. RESULTS

3.1. Spectral tilt across vowels

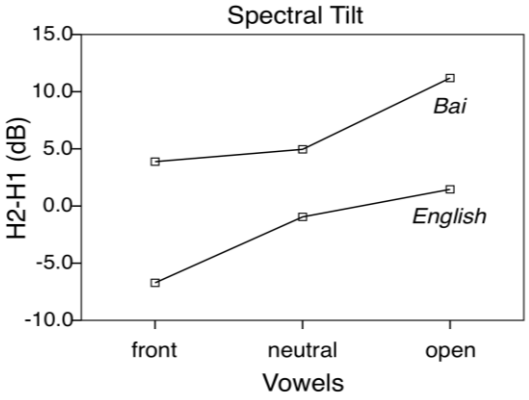
The average spectral tilt for each of the vowel

categories evaluated (front, neutral, and open) as produced by Bai and English infants is summarized in Table 1 below.

Table 1: Average spectral tilt of front, neutral and open vowels by Bai and English infants based on 50 measurements per vowel per language (std. dev.) in months 10-12.

	Front	Neutral	Open
English	-6.72 (14.4)	-0.95 (10.3)	1.46 (9.0)
Bai	3.88 (11.4)	4.96 (11.5)	6.68 (11.0)

Figure 1: Spectral tilt across vowels for Bai and English infants.



As illustrated in Figure 1, infants produce open vowels with a higher spectral tilt (indicative of a higher degree of laryngeal constriction, including tongue retraction) than front or neutral vowels. In addition, Bai infants generally exhibit higher spectral tilt than English infants. A Factorial ANOVA confirms a significant effect of language ($F[1,294] = 47.238$, $p < .001$) and vowel ($F[2,294] = 12.398$, $p < .001$) on the spectral tilt values. These results are consistent with the assumption that vowels that are inherently constricted, or especially susceptible to constriction (including tongue retraction), such as low open vowels, tend to be produced with more constricted phonatory settings. Conversely, vowels that inherently involve tongue root advancement, such as front vowels, tend to be associated with less constricted phonatory settings. Even when these vowels are produced with measurable laryngeal constriction, as are many of the front vowels produced by infants in this study, the degree of laryngeal constriction tends to be less, as reflected in the lower spectral tilt values. Finally, neutral vowels, which do not inherently involve tongue root retraction or tongue root advancement, can be produced in slightly advanced and slightly retracted variations, as reflected in spectral tilt average values that are lower than those obtained for open vowels, but higher than those found for front vowels, among infants from both language groups.

Of particular interest here is the fact that Bai infants may produce not only a greater number of constricted vowels than English infants, but also that even when infants from both language groups produce constricted vowels, the Bai infants' vowels tend to be produced with a greater degree of constriction. In order to evaluate whether this tendency is restricted to the end of the first year or whether this tendency may be observed at an earlier age, we conducted subsequent preliminary analysis from 0 to 12 months on the open vowels.

3.2. Spectral tilt across age groups

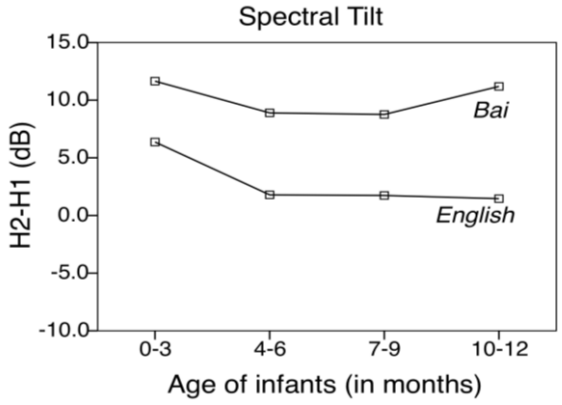
The average spectral tilt of open vowels produced by English and Bai infants at the four age groups evaluated are summarized in Table 2 below.

Table 2: Mean spectral tilt per age group (in months) for English and Bai infants based on 50 measurements per age group per language (std. dev.).

	0-3	4-6	7-9	10-12
English	6.37 (8.5)	1.79 (7.6)	1.73 (5.8)	1.46 (9.0)
Bai	11.65 (5.4)	8.90 (7.3)	8.76 (8.8)	11.19 (8.5)

A Factorial ANOVA indicates a significant effect of language of exposure ($F[1,392] = 88.73$, $p < .001$) and a significant effect of age on spectral tilt ($F[3,392] = 5.141$, $p < .01$). As illustrated in Figure 2 below, the spectral tilt generally decreases from 0-3 months to 4-6 months for all infants. However, while the spectral tilt of English infants at 10-12 months remains lower than at 0-3 months, the average spectral tilt for Bai infants increases again at 10-12 months, roughly equaling the value found at 0-3 months. In addition, the spectral tilt obtained for Bai infants is higher than that of English infants throughout the first year, even at the onset of the first year (0-3 months). In keeping with the physiological constraints of the infant vocal tract, infants from both language groups produce extremely constricted sounds at this age. However, it appears that even at this early point in phonetic development, Bai infants produce sounds with a greater degree of constriction than English infants, possibly reflecting an early attunement to the laryngeal settings of the ambient language.

Figure 2: Average spectral tilt of open vowels per age group for Bai and English infants.



4. DISCUSSION & CONCLUSION

This exploratory study examined the relationship between vowel quality and laryngeal constriction, as measured by spectral tilt (H2-H1) in the utterances of Bai and English infants. We found a systematic relationship between vowel quality and laryngeal constriction that reflects the inherent presence or absence of constriction in these vowels. Moreover, the patterns identified are consistent with what one might predict based on the physiological changes to the vocal tract in infancy, whereby infants acquire the ability to produce less constricted sounds over the first year. Finally, the findings suggest that the ambient language affects the degree of laryngeal constriction produced throughout the first year. English infants, who are learning a language that does not employ laryngeal constriction distinctively, produce less constricted vowels throughout the year than Bai infants, whose ambient language features constricted phonatory settings in its register tone system.

The findings of this study, while suggestive and generally consistent with previous work on laryngeal constriction in infancy, need to be followed up with further, larger-scale analyses of the relationship between vowel quality and laryngeal constriction in the vocalizations of the Bai and English infants.

First, it will be of interest to track the production the three vowel categories throughout the first year for both language groups. Based on the theoretical assumptions of this paper, it is likely that the capacity to produce different categories of vowel is systematically related to the evolving laryngeal capacities of young infants. In the earliest period of the year, when infants are physiologically most predisposed towards laryngeal constriction, it is likely that low open vowels, especially [ɑ], which is inherently retracted, are produced most frequently, followed by neutral vowels. Front vowels, especially [i], are unlikely to be produced at all in the first three months. When this vowel emerges in production, it is likely at a time when infants begin to explore the use of unconstricted phonatory settings. Moreover, studies of laryngeal constriction in infant babbling in the two languages may illustrate an even stronger influence of the ambient language on the use of laryngeal constriction.

5. REFERENCES

[1] Benner, A., Grenon, I., Esling, J.H. 2007. Infants' phonetic acquisition of voice quality parameters in the first year of life. *Proc. 16th ICPhS* Saarbrücken, 3, 2073-2076.

[2] Bettany. L. Unpublished. *Range Exploration of Phonation and Pitch in the First Six Months of Life*. M.A. thesis, University of Victoria.

[3] Crelin, E.S. 1973. *Functional Anatomy of the Newborn*. New Haven: Yale University Press.

[4] DiCanio, C. 2009. The phonetics of register in Takhian Thong Chong. *JIPA* 39, 162-188.

[5] Esling, J.H. 1999. The IPA categories "pharyngeal" and "epiglottal": Laryngoscopic observations of pharyngeal articulations and larynx height. *Lang. & Speech* 42, 349-372.

[6] Esling, J.H. 2005. There are no back vowels: The laryngeal articulator model. *Canadian. J. of Ling.* 50, 13-44.

[7] Esling, J.H., Edmondson, J.A. 2002. The laryngeal sphincter as an articulator: Tenseness, tongue root and phonation in Yi and Bai. In Braun, A., Masthoff, H.R. (eds.), *Phonetics and its Applications: Festschrift for Jens-Peter Koster on the Occasion of his 60th Birthday*. Stuttgart: Franz Steiner Verlag, 38-51.

[8] Vorperian, H.K., Kent, R.D., Gentry, L.R., Yandell, B.S. 1999. Magnetic resonance imaging procedure to study the concurrent anatomic development of vocal tract structures: Preliminary results. *Itl. J. of Ped. Ororhin* 49, 197-206.