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TONE SPLITS AND VOICING SHIFTS IN THAI: PHONETIC PLAUSIBILITY

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Introduction.

If the distinctive tones of present-day Central Thai (Siamese) are the outcome of a series of developments over the centuries from an early simpler Proto-Tai tone system, or even a pristine state of tonelessness, we are beset with a problem common to all diachronic phonology. Can the causes of sound change be found? For Thai, as for some other Asian languages, this problem is complicated and made even more interesting by an apparent intersection of changing tonal features and shifting voicing states of word-initial consonants. It is our wish here to try to shed phonetic light on this aspect of the history of Thai.

In learning their language, children are likely to deviate ever so slightly in pronunciation habits from their adult models in ways that are largely unnoticeable at the time (Vendryes, 1923; Gray, 1939). Insofar as these shifts are not random, they may accumulate gradually over the generations, resulting in sound changes with phonological consequences. Linguists have concentrated on these structural alterations, describing them systematically and purporting to show that, by and large, they are so regular that they can be stated in terms of "laws" for individual languages or language families. Except for noting that most of these changes, once they have been traced, are not phonetically improbable—e.g., /m/ is not likely to become /g/—they seldom find underlying phonetic mechanisms that might have brought these changes about.

With the recent advance of our understanding of the production and perception of speech, it is tempting for the experimental phonetician to believe that phonetic hypotheses on the causes of sound change should be testable in the laboratory (Ohala, 1974). For such research, without any way to resurrect long-dead informants for a brief stint of field work, the most that we can hope to do is to test the phonetic plausibility of these hypotheses by using present-day speakers. It must be stressed that it is only the plausibility of a posited causal relationship between sound change and particular phonetic mechanisms that can be tested.

A number of studies on the plausibility of postulated phonetic mechanisms of change have appeared in recent years. For example, Whalen and Beddor (1989) have published experimental data compatible with an explanation of the rise of a nasal feature in Eastern Algonquian. As for the emergence of distinctive tones, Hombert, Ohala and Ewan (1979) have provided an excellent critical review of the instrumental and experimental work on this topic.

The term *tonogenesis*, apparently first used by James Matisoff (1970, 1973), can mean the emergence of phonologically distinctive tones in a previously toneless language under the influence of certain contextual features. Another use of the term has been as a label for the splitting of old tonal categories into a larger number of tones. J. Marvin Brown (1975) speaks of the "great tone split...that swept through China and northern Southeast Asia nearly a thousand years ago."

During the time of the emergence of its daughter languages, Proto-Tai is generally said to have had four voicing categories for initial consonants and three phonemic tones on "smooth" syllables, i.e., those ending in a nasal, glide, or long vowel, which would all have been inherited by Old Thai (Siamese). If we make our focus for the moment not the tones but the initial consonants, we find the consensus of the various sources (e.g., Li, 1977) to be that the voicing states of some of these consonants changed under the influence of the pitch slopes as the tones emerged. We epitomize the situation with the labial stops:

Proto-Tai	*ʔb	*b	*p	*ph
Central Thai	b	ph	p	ph

We see that in modern Central Thai we have /ph/ from two sources, as is reflected in the Thai writing system. The correspondences are not exactly the same for all Tai va-

rieties; for example, in Chiangmai /b/ > /p/. Our emphasis here, however, is on Central Thai. The phonetic nature of /ʔb/ is problematic (see Erickson, 1975 for a discussion). Haudricourt (1956) makes the rather tempting suggestion of [b^h] as an intermediate stage in the shift from /b/ to /ph/.

With help from the writing systems, study of correlations between tones and initial consonants has led to the positing of tonal splits conditioned by the shifting voicing states of those consonants (Maspero, 1911; Li, 1947, 1977; Haudricourt, 1956). That is, ignoring the special problem of one of the four classes of consonants, the so-called glottalized consonants (see Erickson, 1975), we find that for each tonal category of Old Thai words with initial voiced consonants developed a lower tone and words with initial voiceless consonants, a higher tone. Thus the three Proto-Tai tones on smooth syllables, named simply A, B, and C¹ in the absence of knowledge of their phonetic nature, would have split into six. In fact, given the vicissitudes of the spread of phonological change over related languages, we find that Central Thai, which is the dialect of the Bangkok region and the basis of the official language of Thailand, has only five tones, while other regional dialects and other Tai languages have six or more, with differences among them in pitch contours as well. In a chart adapted from the work of Fang Kuei Li (1977, pp. 24-33), we give an outline of the tonal shifts from Proto-Tai to Central Thai:

PROTO-TAI		CENTRAL THAI	
Tone	Initial	Tone	Examples
A	Voiceless	Mid or rising	paj to go fǎn rain
	Voiced	Mid	naa rice field wan day
B	Voiceless	Low	kǎw old pháa to split
	Voiced	Falling	phǎo father nǎn to sit
C	Voiceless	Falling	kǎw nine nǎa face
	Voiced	High	thǎon belly máa horse

¹ Li also posits tone D on syllables ending in a stop consonant. There is no way of identifying it with any of the other tones. The phonological treatment of modern Thai, however, generally aligns the tones on such syllables with certain tones that occur on smooth syllables.

Aside from these historical hypotheses, it has been known for some time that in human speech the fundamental frequency (F0)² of a syllable beginning with a voiced consonant is likely to be lower, for at least part of its duration, than that of a syllable beginning with a voiceless consonant (House & Fairbanks, 1953; Lehiste & Peterson, 1961). Indeed, it is remarkable that the early historical linguists logically inferred this likelihood without access to supporting physiological and acoustic phonetic research!

For Thai (Gandour, 1974; Erickson, 1975) and other languages (Hombert, 1975), it has been found that F0 is likely to rise upon release of a voiced initial and fall upon release of a voiceless initial; both of these perturbations tend to end and blend in with the prosodic pattern of the syllable as determined by the sentence intonation and, in tone languages, the lexical tone. Other studies (e.g., Umeda, 1981; Kohler, 1982; Ohde, 1984; Löfqvist, Baer, McGarr, & Story, 1989) do not support a clearcut dichotomy between rising and falling perturbations. Rather, the F0 upon release of the voiced stop may in fact be on a level with, or at least not separable from, the rest of the contour; it may even fall a bit, or it may indeed rise; the crucial difference is that it is lower than the F0 onset upon release of a voiceless stop.

Physiological basis. As shown in literature reviews (Erickson, 1975; Ohala, 1978; Hombert et al., 1979), much ink has been spilled in support of various mechanisms that might underlie the F0 differences. Varying amounts of air flow governed by glottal size do not last long enough after stop release to account for the full effect. The role of myoelastic factors has long seemed much more probable. This would have to be some kind of difference in tension of the vocal folds. The problem has been to demonstrate this and tell what the mechanism is. One conjecture was vertical tension (Halle & Stevens, 1971), although it was hard to see how this might be executed, in spite of the finding of a higher position of the larynx for voiceless stops (Ewan & Krones, 1974). We are convinced by the recent work of Anders Löfqvist and his colleagues (Löfqvist et al., 1989; Löfqvist & McGowan, in press) that responsibility lies with varying degrees of contraction of the

² The fundamental frequency of a complex sound wave is equivalent to the repetition rate of the vibrating source. Thus in speech the number of cycles of vibration per second of the vocal folds, given as a number of Hertz (Hz), is the fundamental frequency, which, of course, may vary continuously. It is the primary physical correlate of the sensation of pitch.

cricothyroid muscle used for control of vocal-fold tension to maintain or suppress vibration. Greater amounts of tension to help suppress voicing upon opening the glottis, combined with aerodynamic consequences, will cause higher F0 values in the speech signal.

Perception. The historical argument depends, of course, on the audibility of the F0 differences. Through psychoacoustic tests, Hombert (1975) showed that F0 movements of comparable magnitude are discriminable. It has also been found that either in somewhat exaggerated form (Haggard, Ambler, & Callow, 1970) or within more or less normal ranges (Fujimura, 1971; Abramson & Lisker, 1985; Kohler, 1985; Silverman, 1986; Whalen, Abramson, Lisker, & Mody, 1990) F0 perturbations can influence judgments of voicing in stops in such languages as English, Japanese, and German.

Goals of this study. If we assume these findings in production and perception to be universal and thus relevant to Southwestern Tai, the branch that gave rise to Thai, we might suppose that speakers of the language, already accustomed to the three-way tonal contrast of Proto-Tai, were psychologically receptive to the pitch fluctuations normally occurring with voicing distinctions.³ We might suppose that attention was gradually shifted from the increasingly unstable voicing states of the initial consonants to the effects of the pitch perturbations on the following vowels. Increasing awareness of the perturbations could have led, through auditory feedback to production mechanisms, to enhancement of the effect by means of articulatory reinforcement and exaggeration of pitch differences. In this way, phonemicization of the pitch fluctuations came about, yielding an increase in tonal categories and helping to keep the old lexical classes apart, while the consonantal voicing categories decayed, shifted, and even coalesced.

To examine the plausibility of the foregoing historical arguments, we carried out experiments on the possible perceptual interaction between tones and initial stops consonants in the Thai language of today. That is, on the assumption of *diachronic* interaction between initial consonants and tones, we tested two hypotheses on speakers of modern Central Thai: (1) Perturbations of fundamental frequency should affect the perception of voicing distinctions in initial stop consonants. (2) The voicing states of initial stop consonants should affect the perception of tones. It must be understood that for both hypotheses we are not saying that the factors

³ J. Marvin Brown (1975, pp. 43-45) has offered some very interesting speculation on the matter.

mentioned will be *primary* for the perception of these phonological distinctions. Rather, support for the hypotheses will be obtained if the boundaries between the perceptual categories are significantly affected. So as to have incremental control over the dimensions of interest to us, we followed the common practice of using synthetic speech.

Experiment I: Voice Onset Time

An underlying assumption in these experiments, borne out by earlier work, is that the voiced, voiceless unaspirated, and voiceless aspirated stops of Thai lie along a dimension of voice onset time (VOT), namely, the temporal relation between the closing of the glottis for audible pulsing and the release of the occlusion of the initial stop (e.g., Lisker & Abramson, 1964; Abramson & Lisker, 1965; Abramson, 1989). For /b d/, voicing begins somewhat before the release, yielding "prevoicing" or "voicing lead," i.e., audible glottal pulsing during the occlusion. For /p t k/, voicing begins at the release or shortly thereafter. For /ph th kh/, voicing begins somewhat after the release; during the resulting "voicing lag," turbulent air coming through the open glottis excites the supraglottal vocal tract, yielding aspiration. These differences along the VOT dimension have not only been found in the acoustic signals but have also been shown to be perceptually relevant.

Procedure. In Experiment I we replicated the old work on the perceptual efficacy of VOT in Thai in order to establish a baseline for the testing of our two hypotheses. Using the Haskins Laboratories parallel-resonance synthesizer, we made as our basic pattern for all stimuli a set of formant⁴ transitions appropriate to the labial place of articulation⁵ followed by three steady-state formants appropriate to the Thai long vowel /aa/. We set the voice source of the synthesizer to produce 37 VOT variants, ranging from 150 msec before the stop release to 150 msec after the release. We did this in 10-msec steps except for the region around the release, where we used 5-msec steps from 10 msec before the release until 50 msec after the release. Thus, stops with VOT before the release, i.e., voicing lead, simulated varying amounts of closure voicing. All the

⁴ A formant is the acoustic consequence of a resonance of the vocal tract. An array of formants at different resonant frequencies will specify the spectrum of a vowel.

⁵ As the vocal tract changes its shape through articulatory movement, the formants will necessarily shift in frequency. Such formant "transitions" furnish perceptual cues to place of articulation.

rest of the stimuli had a silent labial closure. All VOTs after the release had their upper two formants excited by a noise source and no excitation in the first formant for the period of voicing lag to simulate aspiration with an open glottis. We made a satisfactory mid tone by means of a level F₀ at 120 Hz with, for naturalness in utterance-final position, a slight fall at the end (Abramson, 1962). We prepared eight tape-recorded randomizations of the synthetic stimuli with two tokens of each one in each of the test orders. Thus, each subject could have responded 16 times to each stimulus; however, depending on their availability, the listeners varied somewhat in how many tests they took. We played the tests through headphones to 48 native speakers of Central Thai at Ramkhamhaeng University and the now defunct Central Institute of English Language for identification in Thai script as /baa/ 'teacher,' /paa/ 'to throw,' or /phaa/ 'to lead.'

Results. The results of Experiment I are given in Figure 1. The ordinate shows the percentage of responses to each stimulus as one of the voicing states, which are indicated by the coded lines. The VOT values of the stimuli are arrayed at the bottom along the abscissa.

BASELINE EXPERIMENT

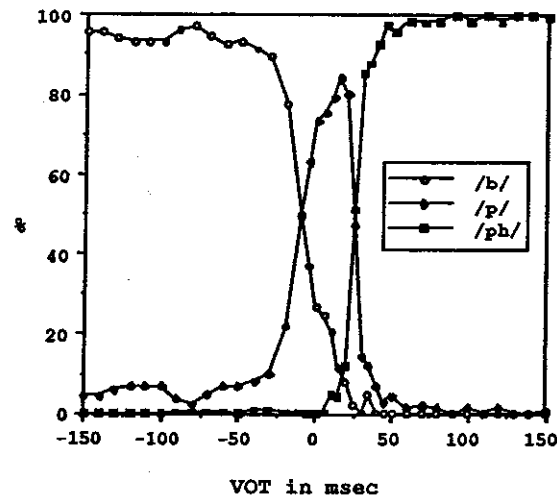


Fig. 1. Identification of synthetic labial stops varying in voice onset time. N=440.

The category boundaries at the 50% crossover points, -7 msec for /b/-/p/ and 26 msec for /p/-/ph/, are very similar to those found in earlier work (Abramson & Lisker, 1965; Lisker & Abramson, 1970). Probably because of shortcomings in the synthesis, the /p/ category does not reach as high a peak as the other two. With these data in hand, we were ready to go on to Experiment II to test the first hypothesis.

Experiment II: F0 Shifts and VOT

Procedure. We then turned to the matter of the effect of initial pitch perturbations on the identification of voicing states. We made our stimuli by varying the features of VOT and the extent of initial F0 shifts in the syllable pattern of Experiment I. With the data from Experiment I as a baseline, we chose nine VOT values to span the three voicing categories: -100, -20, 5, 10, 15, 20, 25, 30, and 80 msec. We imposed five F0 onsets upon each VOT variant. In addition to a flat onset at the 120 Hz level of our mid tone, we also had two downward shifts from 130 Hz and 140 Hz, as well as two upward shifts from 110 Hz and 100 Hz. Production data (Erickson, 1974) suggested that this 40-Hz range was reasonable. The shifts started at the first glottal pulse after the release of the stop and lasted 100 msec.⁶ We presented three randomizations of the stimuli through headphones to 46 of our original listeners for identification as /b/, /p/, or /ph/ in Thai script, as in the previous experiment.

Results. The results of Experiment II are given in Figure 2. From top to bottom the three graphs show identification of the stimuli as /b/, /p/, and /ph/, respectively. Along the abscissa are displayed the VOT values, ranging from -100 msec to 80 msec. The ordinate shows the percentage of responses given to the various F0 conditions for each of the VOT values. There is a coded line for each of the F0 onsets.

An analysis of variance showed a high level of significance for the interaction between voicing state and F0 onset for /b/ and /p/: $F(8, 360) = 2.67, p < .008$. Looking at the top graph, we see that the number of /b/ responses increases systematically as the initial F0 value decreases. That is, as the F0 value goes down, more stimuli are identified as /b/ at a later VOT value. In the middle graph, we again find an effect but in reverse. Higher F0 onsets increase the number of /p/

responses and thus yield earlier perceptual crossovers between /b/ and /p/. The bottom graph, however, shows a very tight clustering of the curves for /ph/ with no obvious effect of F0; this effect is not significant.

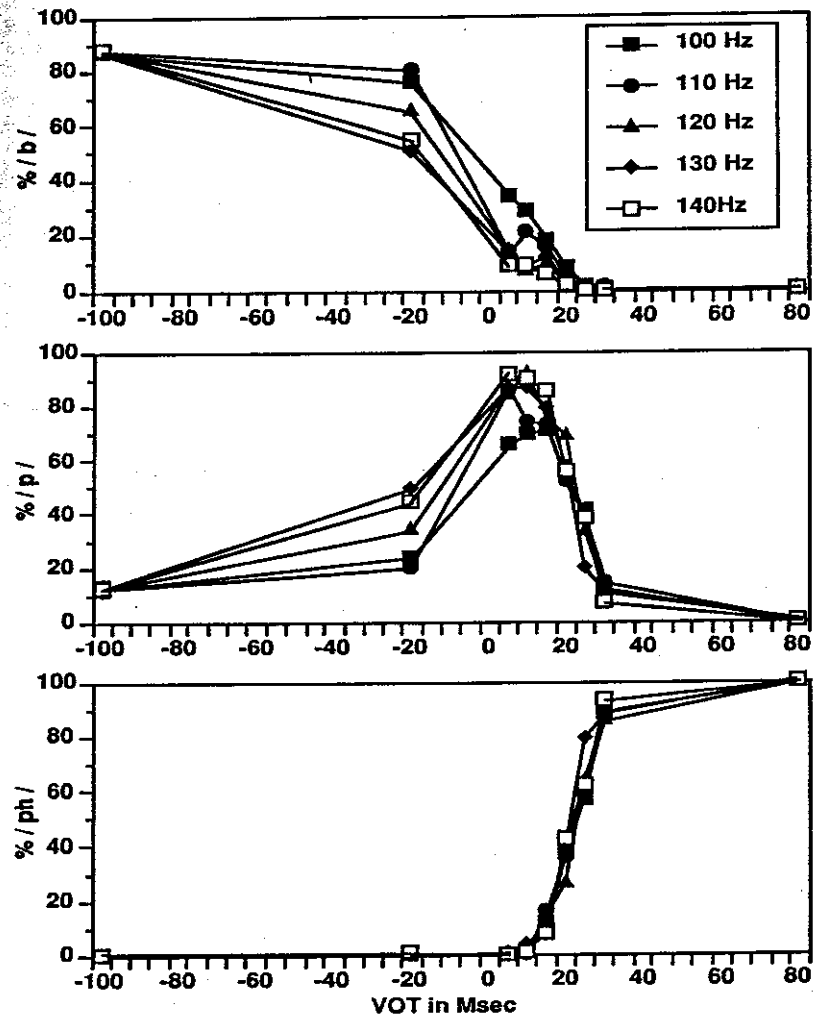


Fig.2. Effects of F0 shifts on identifications. N=224.

⁶ Actually, we also used two other durations for the shifts, 50 and 150 msec. Inasmuch as we found no significant difference for the durations, we are presenting our data for the middle value only, 100 msec.

Experiment III: Voicing States and Tone Labels

We turned next to our second hypothesis, the one asserting that the voicing states of initial consonants will affect category boundaries for tones.

Procedure. To examine this question, we used a fan-shaped series of F0 contours with a common origin, which had previously (Abramson, 1978) been shown to be perceptually divisible into the three static tones, high, mid, and low. The 16 tonal variants all started at 120 Hz and moved to end points ranging from 152 to 92 Hz in 4-Hz steps. We synthesized syllables with VOT values suitable for /b p ph/ and formant frequencies for the vowel /aa/. The syllable meant to be heard as /baa/ had a VOT of -100 msec, /paa/, 0 msec, and /phaa/, 80 msec. The onset of each F0 contour began with the release of the stop. For /b/, the simulated closure, i.e., the 100 msec of voicing lead before the release, was at a level F0 of 100 Hz. Several randomized test orders were played through head phones to nine native speakers of Central Thai at The University of Massachusetts in Amherst.⁷

Results. The subjects fully accepted the three VOT values as the intended voicing states. Their tone labels are given in Figure 3. From top to bottom, the three graphs show how the listeners labeled the F0 contours as low, mid, and high tones respectively. The coded lines show the effects of the perceived voicing states of the stops on the tonal judgments. Along the abscissa are given the final F0 values of the tonal variants. Each point plotted gives the percentage of responses to that stimulus as the tone named on the ordinate.

An analysis of variance for the areas under the curves in the top graph shows a significant effect of the voicing states on the low-tone responses: $F(2, 16)=4.33$, $p < .04$. As shown by a post-hoc t -test, the main effect ($p < .05$) is that initial /b/ yielded a greater number of low-tone responses than the other two stops. We can see from the 50% crossover points that the final F0 can be higher for /baa/ than for /p ph/ and still be identified as a low tone.

The data plotted for the mid tone in the middle graph also show a significant interaction in an analysis of variance between voicing states and tone responses: $F(2, 16)=8.93$, $p < .003$. Post-hoc t -tests ($p < .01$) show that it is /phaa/ that has a larger number of mid-tone responses than the other two syllables.

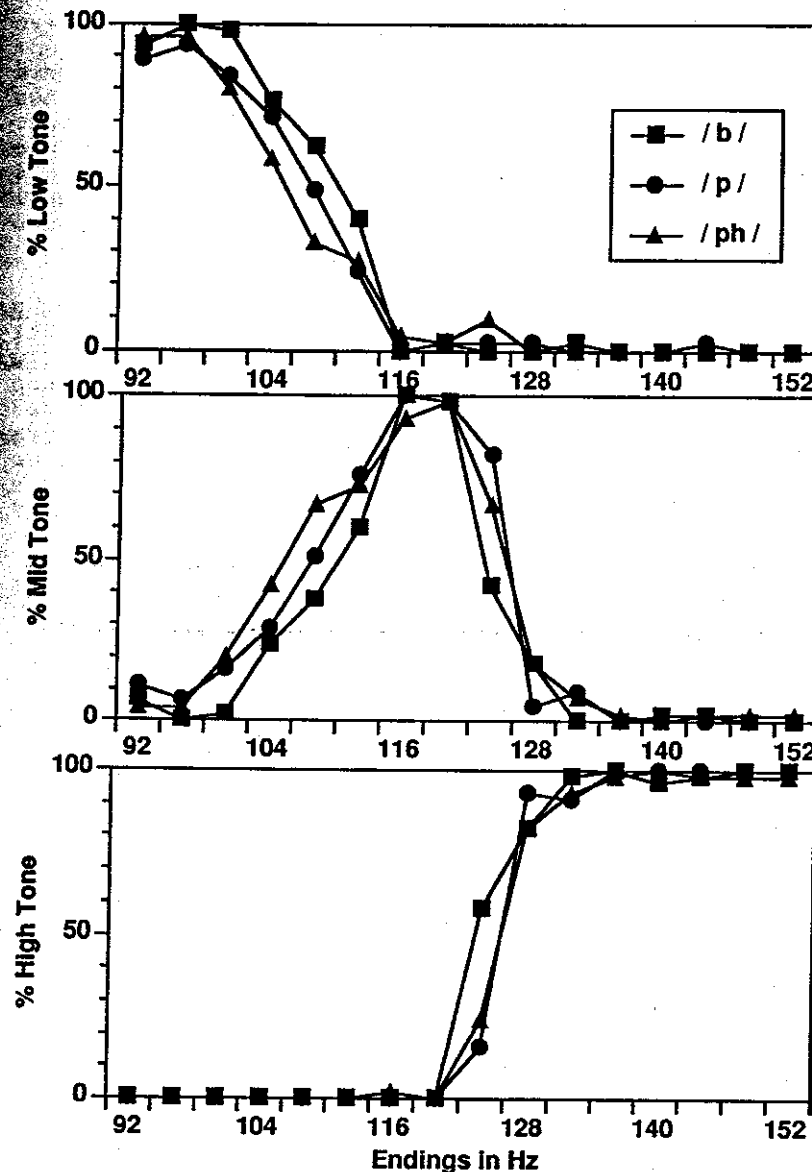


Fig. 3. Effects of voicing states on tone labels.

⁷ Unfortunately, we had to prepare this experiment after we had both returned from Thailand, so we had to use a much smaller number of subjects; nevertheless, we obtained enough data for statistical treatment.

As for the high tone in the bottom graph, again an analysis of variance shows a significant interaction: $F(2, 16)=8.23$, $p < .004$. Just as for the low tone, here too post-hoc t-tests ($p < .01$) show that the effect comes from the difference between /b/ and the other two stops. That is, initial /b/ gives a higher number of high-tone responses than /p/ or /ph/. Also, note the earlier 50% crossover point for /b/ between the mid and high tones. The crossover points for /p/ and /ph/, however, lie on top of each other.

Conclusion

It is clear from our data that fundamental-frequency perturbations can affect the placement of perceptual boundaries along the dimension of voice onset time. It is also true that the voicing states of initial stop consonants can affect the labeling of a continuous series of fundamental-frequency contours as tones. There are details of the various interactions, such as the seemingly paradoxically opposed boundary shifts for /baa/ with the low and high tones, that will require more thought and, perhaps, further investigation.

By and large, then, our perceptual data seem to support the historical arguments concerning interactions between tone splits and voicing shifts. As pitch perturbations loomed larger in the consciousness of the community and gradually took on a distinctive function, one might suppose that the voicing states of initial consonants would have been reassessed perceptually and rearticulated to furnish new production norms. A combination of these factors would have brought about shifts in tonal and consonantal categories.

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