HISTORICAL DEVELOPMENT OF TONE PATTERNS

JEAN-MARIE HOMBERT and JOHN J. OHALA
University of California, Santa Barbara
University of California, Berkeley

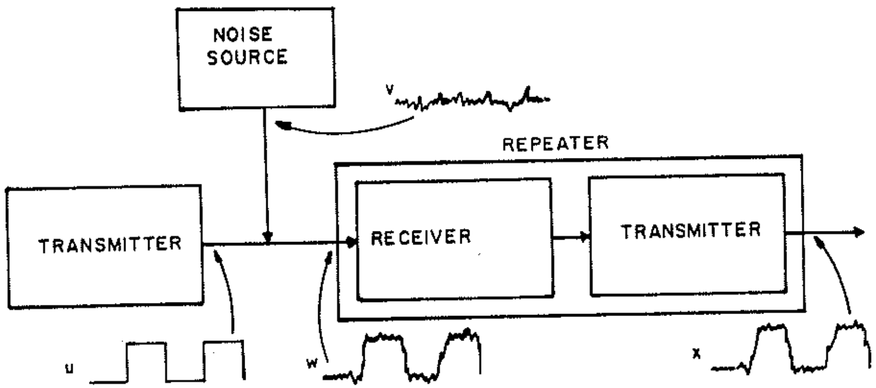
INTRODUCTION

The Phonetics Laboratory at UCLA and the Phonology Laboratory at Berkeley have been engaged in studies of various aspects of tonal development ("tonogenesis") for the past 5 or 6 years. This paper constitutes a progress report on some of this research.

We should first explain our approach to tonogenesis -- or any other sound change which is found in many languages. Our primary interest is not tonogenesis in any particular language but tonogenesis as a universal or potentially universal process. Thus we are interested in every case of tonogenesis. Observing similar patterns of tonal development in many languages quite distant from each other chronologically, geographically, and genetically, we of necessity look to the universal physical properties of the human speech production and speech perception system to explain the origin and directionality of these sound patterns. We will not attempt to further justify the utility of this approach except to point out that it has had considerable success in historical phonology for a century or so; see, e.g., Passy (1890), Rousselot (1891), Lindblom (1975), Lehiste and Ivić (1963, 1977), Janson (1977).

One of the consequences of this approach -- quite surprising to some -- is that we feel justified in studying the physical causes of tonal development by examining modern languages that need not be tonal, e.g., English, French, Russian, or Japanese. As will be demonstrated, it is not at all difficult to find what we metaphorically call the *seeds* of many sound changes, including tonogenesis, in the speech of present-day speakers. Although the factors causing tonogenesis, that is, the seeds of tonogenesis, may have germinated and blossomed several centuries ago in Middle Chinese, Early Vietnamese, Punjabi, etc., nevertheless these same seeds may be found dormant in the speech of today's speakers speaking today's languages.

A graphical representation may be helpful in conveying an idea of how physical constraints of the speech mechanism can influence the form of speech via sound change in a purely mechanistic, non-teleological, way. We can liken speech communication to a transmission line with relay stations or "repeaters", as in Figure 1:

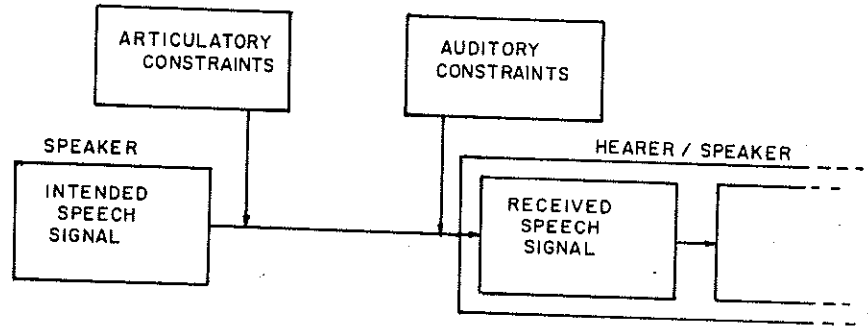


Transmission line with repeater, used as an analogue of the speech communication process.

A transmitter sends out a signal, u, to which noise, v, is added, yielding the distorted signal, w = u + v, which is picked up by the receiver, part of the repeater unit. It is the distorted signal, w, which is retransmitted as the signal, x, sent to the next repeater.

In the case of human speech, important sources of distortion are

the constraints of the transmitting and receiving systems, that is, the vocal tract and the auditory system. This is represented in Figure 2:



Schematic representation of how articulatory and auditory constraints can introduce distortions in the speech signal.

The speaker, although intending to produce a certain pronunciation, may, due to vocal tract constraints, actually produce something slightly different, that is, a speech signal with unintended additional features of pronunciation.

Auditory constraints can affect pronunciation somewhat differently. Parts of the speech signal which are auditorily ambiguous, that is, those which, as far as the listener is able to tell, may have been produced by any of two or more distinct articulations, may be articulatorily re-interpreted by the listener when he repeats the signal (Sweet 1891:238, Jonasson 1971).

There are these two ways, then, that the speech signal, by the time it is received by the listener, may contain elements not put there by the speaker. The listener does not have independent access to the mind of the speaker and so cannot differentiate between parts of the signal which were intended from those unintended. When he repeats the words he hears, he may pronounce intentionally those features which were unintended by the speaker he first heard the words from. We would maintain that through such mechanisms "mini-sound changes" occur all the time -- potentially, at least, every time someone speaks and someone else listens. Naturally, most of these changes -- misunderstandings, we might call them -- are corrected sooner or later. It is the ones that aren't which go on to become regular "maxi-sound changes" via normal non-phonetic social transmission of patterns of pronunciation.

There are at least the following four steps that must be taken to show that a particular aspect of tonogenesis (or any other sound change) is a natural, potentially universal sound change:

1. It must be shown to be wide-spread among the languages of the world.
2. It must be possible to find its "seeds", i.e., manifestations of systematic variations in pronunciation of the same type and same directionality, in the articulatory or perceptual behavior of any speaker whose speech offers the proper phonetic conditions.
3. It must be shown that these variations are unintended by-products of other intended elements of pronunciation.
4. It must be shown that listeners can detect these variations.

Our claims, then, can be falsified at any one of these steps. We are constantly in search of counterevidence ourselves but we ask the help of all interested phonologists in this task.

TONAL DEVELOPMENT DUE TO CONSONANTAL INFLUENCE

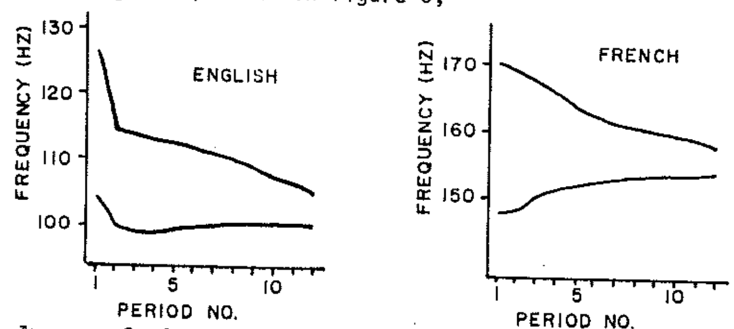
The first pattern we will discuss is one which was first noticed by Maspero (1912) and Karlgren (1926) and extensively documented by Haudricourt during the past 30 years (Haudricourt 1954, 1961, 1971), namely, that represented schematically in (1):

(1) pV → pV́
bV → pV̀

Sequences of voiced obstruent + vowel give rise to low tone on the vowel; voiceless obstruent + vowel give rise to high tone, usually with concomitant neutralization (to voiceless) of the voicing contrast in the obstruents. This process has been extensively documented in Sino-Tibetan, many languages of Southeast Asia, and some languages of Africa (Hombert 1975a).

As for the seeds of this change, we're sure most readers are familiar with the extensive phonetic literature showing small but very consistent differences in pitch on the vowels following voiced and voiceless consonants in English, Russian, Swedish, Japanese, etc. (Ohala 1973, Hombert 1975a, Jeel 1975).

One question that came to mind in examining this pattern was whether in addition to voicing, degree of aspiration also contributed to these pitch variations. We measured pitch after voiced and voiceless stops in the speech of speakers of French and English since the stops in these languages have different phonetic properties: English voiceless stops are far more aspirated than those in French (although our study showed French /p t k/ are by no means completely unaspirated, as the usual textbook descriptions would imply). The English voiced stops, often phonetically voiceless in word-initial position, were uttered in a context that would tend to guarantee their being voiced. The resulting data, shown in figure 3,



Average fundamental frequency measurements in Hertz (vertical axis) of vowels following /p t k/ (upper curve) and /b d g/ (lower curve) as a function of glottal period starting from vowel onset (horizontal axis) for one male speaker of English (left graph) and one male speaker of French (right graph).

suggest that degree of aspiration does not significantly affect pitch; the relevant feature is presence or absence of voicing, as was stated in the traditional works on tonogenesis. (For further details of this study see Hombert and Ladefoged 1977 and Hombert 1978.)

Before discussing the physical causes of this effect we should mention another pattern, namely, that the voicing of a non-glottal obstruent can induce a distinctive tone on the vowel following, not on the vowel preceding. Most of the cases discussed in the literature are in accord with this. Moreover, virtually all instrumental phonetic studies of consonantal effects on vowels have failed to find any influence of the voicing of non-glottal consonants on the pitch of vowels preceding them (Hanson 1975, Jeel 1975).

Regarding the physical causes of these pitch perturbations, our investigations are still incomplete although we feel we have made some progress on the problem. Previously it was thought that aerodynamic differences created by the voiced/voiceless distinction would account for the pitch differences. We can say with some confidence that aerodynamic factors -- as we currently understand them -- cannot account for these pitch variations. This judgment is based on an examination of previously obtained aerodynamic data and on our own computer simulation of aerodynamic events in speech (Ohala 1976 and 1978). If it is not aerodynamic factors which perturb pitch, logically it has to be due to variations in the state of the vocal cords (their tension and/or mass) since that is the only other factor affecting the rate of vibration of the vocal cords. The question is, *how* is the vocal cords' state affected in this case? The best hypothesis we have so far is that variations in larynx height are responsible. The larynx is slightly higher for voiceless obstruents than for voiced obstruents (Jespersen 1889, Ewan and Krones 1974). Other studies have shown that larynx height varies with pitch (Ohala 1972). If this variation reflects causal factors our case is complete. Unfortunately we have not yet been able to forge this final link in our argument. We believe the larynx is lowered during voiced obstruents in order to enlarge the oral cavity so that oral air pressure may be maintained at a level lower than subglottal air pressure; this is necessary if voicing is to continue during the obstruent closure. Of course, the larynx lowering should be greatest at the end of the obstruent closure and current evidence shows that it is (Ewan 1976a). This helps to explain why obstruents may affect only the pitch of the following, not the preceding vowel.

Although non-glottal consonants only affect following vowels, there is evidence that glottal consonants [ʔ h] may induce tone on preceding vowels and, presumably, following vowels as well. We have phonetic data from Arabic, a language that has word-final [ʔ] and [h], that [ʔ] elevates the pitch on the preceding vowels and [h] lowers the pitch on preceding vowels (Hombert 1976c). This pattern parallels the influence of these two consonants on the development of tone in Vietnamese and other languages.

To round out this case we had to determine whether such small consonantally-induced pitch changes were audible or not. In a number of psychophysical tests involving American English listeners -- probably the least skilled listeners where pitch variations are concerned -- we found these small pitch perturbations were detectable (Hombert 1975a).

TONAL DEVELOPMENT AND VOWELS

One point that disturbed us as a potential disconfirmation of our claims regarding consonantal involvement in the development of tones is that vowel quality is also known to affect vowel pitch by about the same magnitude as the obstruents -- higher pitch on high vowels, lower pitch on low vowels -- but there seems to be no consistent pattern of vowel quality leading to tonal development. There are two possible explanations for this, neither of which is sufficiently tested yet although work is underway on them (Hombert 1976d, Hombert and Greenberg 1976).

First we note that consonants usually produce a small pitch contour on adjacent vowels, whereas the effect of vowel quality on pitch is a steady-state higher or lower pitch. Naturally, a rapid change in pitch is more noticeable than a steady-state difference in pitch. The second observation we can make is that the effect of consonants on the pitch of the vowel is in some sense separable from -- in fact it occurs after -- the consonantal segment that produces the effect. This is not the case with vowel quality: necessarily the vowel quality and the changed pitch level caused by the vowel quality occur simultaneously. Perhaps, for a sound change to occur, the phonetic perturbation must be perceptually separable from the perturbing environment in order that the listener have an opportunity to mistakenly regard the perturbation as an independent and therefore intended part of the speech signal.

Additional work by our laboratories on the phonetics and phonology of tone are listed in the references.

ACKNOWLEDGEMENTS

This work was supported by grants from the National Science Foundation, the University of California, Berkeley, Committee on Research, and the Computer Centers and Berkeley and UCLA.

REFERENCES:

Ewan, W. G. 1976a. *Laryngeal Behavior in Speech.* Doc. diss., University of California, Berkeley.

Ewan, W. G. 1976b. "Larynx Movement and Tonogenesis", *Report of the Phonology Laboratory* (Berkeley) 1.29-38.

Ewan, W. G. and Krones, R. 1974. "Measuring Larynx Movement Using the Thyroumbrometer", *Journal of Phonetics* 2.327-35.

Gandour, J. 1974. "Consonant Types and Tone in Siamese", *Journal of Phonetics* 2.337-50.

Hanson, R. J. 1975. "Fundamental Frequency Dynamics in VCV Sequences". Paper presented at the 8th International Congress of Phonetic Sciences, Leeds, August, 1975.

Haudricourt, A. G. 1954. "De l'origine des tons en vietnamien", *Journal Asiatique* 242.69-82.

Haudricourt, A. G. 1961. "Bipartition et tripartition des systèmes de tons dans quelques langages d'extrême orient", *Bull. Soc. Ling. de Paris* 56.163-80.

Haudricourt, A. G. 1972. "Tones in Punjabi", *Pakha Sanjam* 5.xxi-xxii.

Hombert, J.-M. 1974. "Universals of Downdrift: Their Phonetic Basis and Significance for a Theory of Tone", *Studies in African Ling., Suppl.* 5.169-83.

Hombert, J.-M. 1975a. *Towards a Theory of Tonogenesis: An Empirical, Physiologically and Perceptually-based Account of the Development of Tonal Contrasts in Language.* Ph.D. diss., University of California, Berkeley.

Hombert, J.-M. 1975b. "Perception of Contour Tones: An Experimental Investigation", *Proc. Annual Meeting Berkeley Linguistics Society* 1.221-32.

Hombert, J.-M. 1976a. "Phonetic Explanation of the Development of Tones from Prevocalic Consonants", *Working Papers in Phonetics* (UCLA) 33.23-39.

Hombert, J.-M. 1976b. "Consonant Types, Vowel Height, and Tone in Yoruba", *Working Papers in Phonetics* (UCLA) 33.40-54.

Hombert, J.-M. 1976c. "Phonetic Motivations for the Development of Tones from Postvocalic [h] and [?]: Evidence from Contour Tone Perception", *Report of the Phonology Laboratory* (Berkeley) 1.39-47.

Hombert, J.-M. 1976d. "Development of Tones from Vowel Height?", *Journal of Phonetics* 5.9-16.

Hombert, J.-M. 1976e. "Perception of Tones of Bisyllabic Nouns in Yoruba", *Studies in African Linguistics, Suppl.* 6.109-21.

Hombert, J.-M. 1977. "Tone Space and Universals of Tone Systems", *Journal of the Acoustic Society of America* 61.S89.

Hombert, J.-M. 1978. "Consonant Types, Vowel Quality, and Tone", in V. Fromkin, ed., *Tone: A Linguistic Survey.* Pp. 77-111. New York: Academic Press.

Hombert, J.-M. and Greenberg, S. 1976. "Contextual Factors Influencing Tone Discrimination", *Working Papers in Phonetics* (UCLA) 33. 81-89.

Hombert, J.-M. and Ladefoged, P. 1977. "The Effect of Aspiration on the Fundamental Frequency of the Following Vowel", *Working Papers in Phonetics* (UCLA) 36.33-40.

Hombert, J.-M., Ohala, J. J., and Ewan, W. E. 1976. "Tonogenesis: Theories and Queries", *Report of the Phonology Laboratory* (Berkeley) 1.48-77.

Janson, T. 1977. "The Loss of Distinctive Vowel Quantity in Late Latin: The Experimental Reconstruction of Structural Reinterpretation". Paper presented at the 3rd International Conference on Historical Linguistics, Hamburg.

Jeel, V. 1975. "An Investigation of the Fundamental Frequency of Vowels after Various Danish Consonants, in Particular Stop Consonants", *Annual Report of the Institute of Phonetics, University of Copenhagen* 9.191-211.

Jespersen, O. 1889. *The Articulations of Speech Sounds Represented by Means of Analphabetic Symbols.* Marburg in Hessen: N. G. Elwert.

Jonasson, J. 1971. "Perceptual Similarity and Articulatory Reinterpretation as a Source of Phonological Innovation", *Quarterly Prog-*

ress and Status Reports, Speech Transmission Lab., Royal Inst. of Technology, Stockholm. STL-QPSR 1/1971.30-41.

Lehiste, I. and Ivić, P. 1963. *Accent in Serbocroatian* (= *Michigan Slavic Materials No. 4*).

Lehiste, I. and Ivić, P. 1977. "The Phonetic Nature of the Neo-Štokavian Accent in Serbo-Croatian". Paper presented at the 3rd International Conference on Historical Linguistics, Hamburg.

Lindblom, B. 1975. "Experiments in Sound Structure". Plenary address, 8th International Congress of Phonetic Sciences, Leeds.

Ohala, J. J. 1972. "How is Pitch Lowered?", *Journal of the Acoustic Society of America* 52.124.

Ohala, J. J. 1973. "The Physiology of Tone", in L. Hyman, ed., *Consonant Types and Tone* (= *Southern California Occasional Papers in Linguistics* 1.1-14).

Ohala, J. J. 1974. "Experimental Historical Phonology", in J. M. Anderson and C. Jones, eds., *Historical Linguistics II. Theory and Description in Phonology* (= *Proceedings of the 1st International Conference on Historical Linguistics, Edinburgh*). Pp. 353-89. Amsterdam: North Holland.

Ohala, J. J. 1975. "A Mathematical Model of Speech Aerodynamics", in G. Fant, ed., *Speech Communication* (= *Proceedings of the Speech Communication Seminar, Stockholm, 1-3 August 1975. Vol. 2: Speech Production and Synthesis by Rule*). Pp. 65-72. Stockholm: Almqvist and Wiksell.

Ohala, J. J. 1976. "A Model of Speech Aerodynamics", *Report of the Phonology Laboratory* (*Berkeley*) 1.93-107.

Ohala, J. J. 1978. "The Production of Tone", in V. Fromkin, ed., *Tone: A Linguistic Survey*. Pp. 5-39. New York: Academic Press.

Ohala, J. J. and Eukel, B. W. 1976. "Explaining the Intrinsic Pitch of Vowels", *Journal of the Acoustic Society of America* 60.S44.

Ohala, J. J. and Ewan, W. G. 1973. "Speed of Pitch Change", *Journal of the Acoustic Society of America* 53.345.

Passy, P. 1890. *Etudes sur les changements phonétiques*. Paris: Librairie Firmin-Didot.

Rousselot, L'abbe. 1891. *La modification phonétique de langage*. Paris: H. Welter.

Sweet, H. 1891. *A New English Grammar*. Oxford: Clarendon Press.