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There Are No Back Vowels: The Laryngeal Articulator Model

JOHN H. ESLING
University of Victoria

1. BACKGROUND

Vowels are usually described as lingually high or low and front or back. This conceptualization implies a model of lingual movement within the dimensions of a square space — four-cornered in two-dimensional terms — with the tongue moving up or down and from front to back. The tongue is usually represented in this model as the articulator responsible for changes in vowel quality along the high-low and front-back dimensions. This can be called the H-L-F-B model. The frameworks of the vowel quadrilateral, or the vowel triangle, have long represented auditory events in an articulatory way for graphic representational purposes. The image of the tongue moving high in the mouth or back in the mouth, however, does not conform with a growing body of articulatory evidence on pharyngeal phonetics. Neither is it as useful an image as it could be for understanding how sound quality is shaped by articulator movement, vocal tract postures, and resulting cavity resonances.

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The principal reason why the H-L-F-B model inadequately represents (and perhaps even mistakenly portrays) the phonetics of the vocal tract is that it assumes oral lingual articulator activity while virtually ignoring laryngeal articulator activity. Furthermore, to the extent that the H-L-F-B model is intended to account for auditory quality, it has misinformed acoustic theory. The assumption that H-L-F-B movement of the tongue drives vowel quality is not entirely adequate because of what has been discovered in recent years about the activity of the laryngeal articulator, controlling the pharyngeal resonator. In fact, the laryngeal articulator can be shown to relate not only to pharyngeal volume but also indirectly to velo-pharyngeal and mandibular settings in addition to lingual movement. The key in the development of a revised paradigm is to integrate the role of the laryngeal articulator between the mechanism of glottal airflow and the oral articulatory mechanism that contains the front vocal tract articulators.

Considering the anatomy and physiology of the oral vocal tract, back is not articulatorily adequate. The premise of backness, at least in the way that it has been imported into phonology, is a map of tongue movement, where the tongue is either high or low, front or back (Jakobson et al. 1952). The implication is that tongue movement determines vowel quality and that the resulting qualities can be associated with degrees of tongue height and of tongue frontedness or backness. This lingually portrayed model, however, is neither anatomically correct nor auditorily specific enough to account for the origins of vowel qualities. It is not strictly anatomically correct that the tongue moves high or low and front or back in the mouth independently of other articulators. And it is not just that these other articulators operate in addition to what the tongue is doing; they can be viewed as interacting integrally with or even predisposing or controlling what the tongue is doing. This control can be viewed at the most basic articulatory level as primarily physiological, but it can also be expressed at the auditory level that these other articulators shape sound quality to an extent that has an even greater impact on overall vowel quality than just the resonances resulting from tongue shape alone. At the front, the articulator responsible for open quality is the jaw; at the back, it is the laryngeal constrictor.

Back as an articulatory direction is a useful designator of movement in the vocal tract, as distinct from front. But as an articulatory phonetic label, back becomes associated with auditory labels to describe vowel quality. In an articulatorily based view of phonetic theory, auditory designations should reflect the directions of physiological movement of the tongue and of other articulators as accurately as possible. But back can no longer be considered adequate as a representation of the way the tongue moves in the rear part of the vocal tract. It is neither physiologically accurate enough to capture the complexity of movements that have been shown to characterize the interaction of the oral and laryngeal vocal tract, nor phonetically sufficient to carry all of the auditory labels that are now known to be associated with changes in oral and laryngeal vocal tract quality.

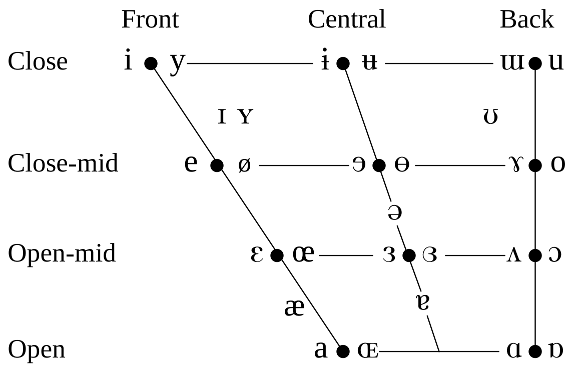


Figure 1: The 1996 IPA Vowel Chart (IPA 1999:ix)[1]

1.1. The lingual oral model

Recognizing that there are auditory, articulatory, and acoustic motivations for representing vocalic relationships in different ways, it may be helpful to use the vowel chart of the IPA to consider why the vowels are represented as they are, symbolically and spatially (Figure 1). This has been a very serviceable model for generations of phoneticians and linguists. It captures particularly well the relationship between lip rounding and tongue position. This 1996 version of the IPA vowel chart is virtually identical to the chart that was published in 1926 in *Le maître phonétique* by Paul Passy and Daniel Jones. The number of symbols is identical, and their locations are approximately the same. The 1926 representation of the vowel space was an innovation, using Roman alphabetic characters instead of the iconic symbols used by Bell (1867) and Sweet (1877). It became the basis for the Cardinal Vowel System developed by Jones (1956). The inventory of symbols used in the 1996 vowel chart is essentially the same as the set used by Abercrombie (1967:151–162) for the Cardinal Vowels.

Bloch and Trager (1942) and Trager and Smith (1951) outlined the vowel space as a three-by-seven grid: front, central, back; by seven levels of height — high, lower high, higher mid, mean mid, lower mid, higher low, low. The purpose of the seven levels was to allow four to represent tense vowels (high, higher mid, lower mid, low) and three to represent lax vowels. This tabular representation was devised as a combination of Sapir's (1916) system and the IPA system (which appeared as *The principles of the IPA* in 1949). The IPA system and Trager's formulation have essentially the same three-by-seven primary degrees of difference found along their two axes, and both are intended to account for distinctions in auditory space. The difference is in shape and in the notion of structural contrastiveness. In the descriptive linguistic structuralist tradition, Trager's

[1] In Figures 1, 2, and 5, where symbols appear in pairs, the one on the right represents a rounded vowel.

elaboration of descriptive categories allowed fine auditory distinctions to be mapped with reference to a (square) scheme whose cells could be minimally distinguished from each other by one parameter. In Trager's (1972) vowel table, every cell of the table was filled, with symbols for unrounded and rounded counterparts, giving a total of 42 sounds/symbols, plus six semivowels. Such a scheme lent itself well to the development of binary distinctive features, by virtue of its structure more than for its articulatory basis, since binary features tended to associate auditory distinctions with acoustic properties of the sound (Jakobson et al. 1952).

Trager's symbols can be further modified by the use of raised, lowered, advanced, and retracted diacritics (Trager and Smith 1951:11). As in the IPA system, however, *raised* as a general articulatory label implies that the tongue operates in the same way at the front of the mouth as in the back, and *retracted* as a general articulatory label implies that the tongue moving back in the case of a close (high) vowel is the same parametric change as the tongue moving back in the case of an open (low) vowel. In Trager's H-L-F-B system, the term "lowered" implies that an open (low) front articulation and an open (low) back articulation differ by one parametric adjustment of the tongue (leaving lip position aside for the moment).

The vowel chart as it stands, however — representing the tongue moving in four directions within a box — inadequately accounts for the role of the laryngeal articulator in affecting vowel quality, tends to confuse the role of the jaw at the front of the vocal tract with the role of the laryngeal articulator at the rear of the vocal tract, and tends to confuse those two very different articulators at the "back" of the vocal tract with each other. The key problem is the issue of how to link the oral articulator with the laryngeal articulator and to explain their combined influence on vowel quality and voice quality. The tongue is not the only articulator that determines vowel quality. This is widely understood, but the relationship between lingual physiology and targets on the vowel chart has not been clearly elucidated. In fact, there are a surprisingly small number of articulators that do account for the parameters that specify the articulatory and auditory shape of voice quality and vowel quality. They comprise the lips, the jaw, the tongue, the velo-pharyngeal port, and the larynx (including the glottal region, and the pharynx within the laryngeal constrictor mechanism). Of these, the distinction between the oral articulator — including the tongue (lingual articulation) and the lips — and the larynx (laryngeal constriction) is the most important in determining the quality of a vowel, not to mention of the voice in general. The position of the tongue in the oral vocal tract and the state of the laryngeal constrictor in the laryngeal (including the pharyngeal) vocal tract both have to be considered in specifying vowel quality. The position of the jaw affects vowel quality, but mainly in the case of front vowels, as the jaw is hinged at the back and opens at the front. Lip shape and the state of the velo-pharyngeal port also contribute to vowel quality, but these are either naturally associated with particular tongue and jaw positions (as in the case of spreading with primary vowels in the upper-left corner of the vowel chart and of rounding with primary vowels in the upper-right corner of the vowel chart) or added by coupling a resonating cavity that does not change shape (as in the case of nasal vowel quality).

1.2. The oral-and-laryngeal model

The research carried out in the Phonetics Laboratory of the Department of Linguistics at the University of Victoria over the past decade demonstrates how the laryngeal articulator functions in a range of languages, how its function differs from what was formerly presumed, and how the interaction of the oral and the laryngeal articulators can be remapped in phonetic theory. This paper presents a series of illustrations of various articulations in the larynx, taken laryngoscopically so that all the principal articulating structures are visible from above during speech. This technique of observation provides images that give a clear picture of articulator movements from the glottis into the pharynx and of how these laryngeal articulations interact with well-known oral activities (well-known because they have been more commonly observed in phonetic research and modelled based on increasingly available data).

The effect of the results of this research is to shift away from a model where the vowel space is blocked into a square paradigm, governed, in theory, by tongue movements in an oral vocal tract that extends from the glottis to the front of the mouth, to a model where the vocal tract is separated into two different resonating cavities, one primarily laryngeal and the other primarily oral. The laryngeal component is not primarily lingual. It does, however, involve one of the three principal directions of movement of the tongue — retraction. The other two principal directions of movement of the tongue are oral — raising and fronting. The retracting, raising, and fronting components interact, but the resulting vowel space is remapped into a distinctive three-way space, with the retracting component earlier in the speech production chain and responsible for qualities in the lower-right corner of the vowel chart.

In the lingual articulator model, which corresponds in acoustics to the source-filter model, the airstream passes through the glottis, where it is shaped by voicing or the lack of voicing or by closure, to the oral cavity, governed largely by the posture of the tongue, where it is modified by the effect of the various cavity volumes resulting from the changing shape of the tongue. In this paradigm, the tongue is the active articulator from the pharynx to the teeth (and potentially even the lips in the case of linguolabial articulations). Another problem with the lingual model is that glottal action is ill-defined. In the laryngeal articulator model, the airstream passes through the glottis, which is either open for breath or adducted for voicing, into the pharynx, which is controlled by the active articulation of the aryepiglottic constrictor mechanism. This aryepiglottic, laryngeal constrictor is responsible both for the closing of the glottal passage and, in conjunction with the raising of the larynx itself and the retraction of the tongue, for the changing volumes of the pharyngeal cavity. In this paradigm, the tongue is not the primary articulator responsible for pharyngeal articulation; the primary mechanism is a laryngeal one. In this model, the active articulator(s) are the aryepiglottic folds, effecting stricture against the epiglottis as the passive articulator. Beyond the laryngeal constrictor, oral articulations are effected by the tongue, but various combinations of oral and laryngeal shaping of the airstream are continually possible. In this revised paradigm, the tongue is the active articulator from the uvula to the teeth (and potentially the lips).

To resolve the issue of integrating the laryngeal articulator into vowel and voice quality description, for physiologically as well as for auditorily motivated reasons, back articulations and qualities can be separated into raised and retracted articulations and qualities. This distinction is shown in Figure 2, in which the front, raised, and retracted sectors of the chart have been separated from each other. This three-way division leaves a set of central vowels in the middle of the space. The main purpose of dividing the chart into three working areas, along physiological lines, is to designate primary elements of vowel quality from elements of potential secondary colouring, especially to show that retraction, motivated by laryngeal constriction, can be a strong influence on other areas of the chart. Front, motivated by fronting the tongue, is the same as on the IPA chart in Figure 1. Most of the modifications to front vowel quality, apart from degree of frontedness, are a function of jaw position, not of lingual setting. These qualities range from close to open, so that the major difference between [i] and [a] can be summarized as a difference in jaw openness. The movement of the tongue to a high back position is better thought of as raised. High is not a bad designation of this movement, because the tongue is indeed pulled high and back in the mouth, but back can be confused with retraction, which is a function of laryngeal constriction. It is not strictly parallel to say *close back* in the same way as *close front* because close refers to jaw position, and jaw position is a more relevant parameter for articulatory quality at the front of the mouth than at the rear of the mouth. Similarly, the labels *close* to *open* are retained at the front, while the label *retracted* is added to the lower-right corner of the chart, where jaw opening is subordinate to the effect of laryngeal constriction. Although raising and retracting of the tongue both occur at the rear of the mouth, raising describes the positioning of the tongue when it is high (pulled upward and backward), while retracting describes the lingual component in the response to the sphinctering mechanism that closes the larynx.

2. Integrating Lingual and Laryngeal Anatomy

In the articulatory-auditory-acoustic relationship between the tongue and the laryngeal system, there are three arguments that stimulate a rethinking of the conceptual vowel space. The tongue is partly oral in its location (attached to the jaw) and partly laryngeal (attached to the hyoid bone). The laryngeal system is

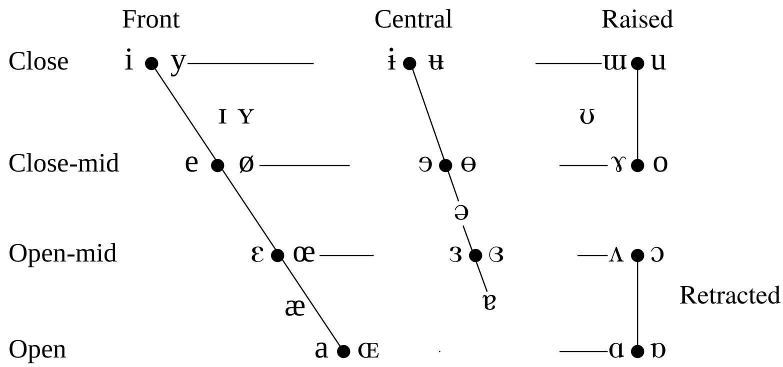


Figure 2: Revised vowel chart, separated into regions: front, open, central, raised, retracted

responsible for a variety of auditory-acoustic outputs that are difficult to attribute to the oral articulator. Infants, in their earliest production of speech, begin learning how to manipulate the laryngeal component first.

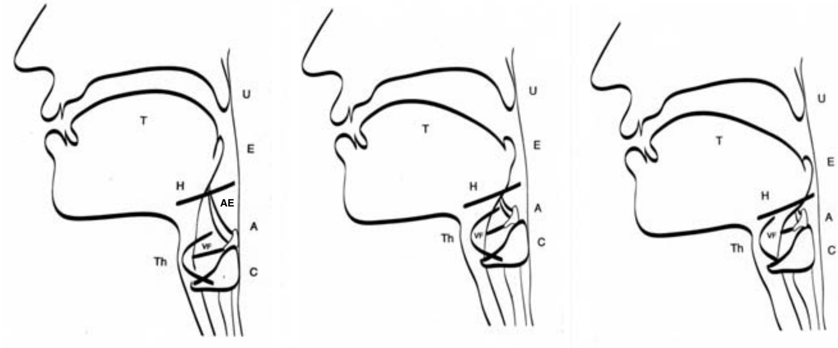
2.1. Lingual physiological actions

Anatomically, the three directions of lingual movement are attributable to the three major extrinsic lingual muscle groups: the genioglossus, the styloglossus, and the hyoglossus. These three muscle groups, pulling the tongue body forward (genioglossus), up and back (styloglossus), and toward the larynx (hyoglossus), are particularly well illustrated in Kahane (1986:108), along with the geniohyoid muscles, which pull the jaw open. The genioglossus group is divided into posterior, medial, and anterior muscle fibres. The posterior genioglossus is primarily responsible for extruding the tongue out of the mouth (through the teeth and the lips), and the anterior genioglossus is primarily responsible for curling the tongue tip downward in the posture of laminal articulations, so that a combination of both is sufficient to bunch the body of the tongue in the front oral (palatal) space. Detailed electromyographic (EMG) studies of the interaction of these muscles in the production of contrasting vowels have assembled data on these three major directions of movement (Harris et al. 1992; Honda 1996). Stated in terms of a H-L-F-B model, “muscle activity for the vowels conforms reasonably well to the idea of trajectories of pull up and front, up and back, and down and back” (Harris et al. 1992:881). Since the targets in this study were vowels of English, some interpretation is required to map the results onto the vowel chart in Figure 1, which is based on the peripheral values of the Cardinal Vowels (see the charts in Abercrombie 1967:151–162). The key difference in interpreting these results within a laryngeal model is that front is not required to be up in direction, that back is a different phenomenon depending on whether it is raised or retracted, and that this difference matters in articulatory and auditory description.

Honda (1996) divides the lingual articulatory area into four directions, with the anterior genioglossus accounting for [æ]. Honda's results associate the posterior genioglossus with [i], the styloglossus with [u], and the hyoglossus with [ɑ], including jaw and lips components to account for rounding and openness. In the laryngeal model, the presence of posterior and anterior genioglossus activity during [i] in Honda's data can be explained by the requirement to front the tongue body while anchoring the tip behind the lower teeth while the jaw is close. In the case of [æ], the predominance of anterior genioglossus activity and relatively low posterior genioglossus activity can be explained by the jaw being open, so that the tongue tip is still anchored behind the lower teeth, but the tongue body does not need to be as actively fronted as for [i] because the opened jaw, with the tongue attached, achieves that effect. The association of the styloglossus with [u] and the hyoglossus with [ɑ] in Honda's study makes it clear that [u] and [ɑ] are motivated by different articulatory mechanisms and that the mechanism for [ɑ] should be more fully explored. This is because the genioglossus and the styloglossus are primarily tongue muscles; they do not exert a great effect on their origins (the inside of the mandible and the styloid process of the temporal bone, respectively), but rather pull strongly on their insertion (the body of the tongue). The hyoglossus can be considered a muscle of the hyoid bone, and like the other suprahyoid muscles, it can be considered to play a role in raising the larynx. Thus, both its origin (the hyoid bone) and its insertion (the body of the tongue) can be moved when it contracts. This chain-link relationship is crucial to understanding how the mechanism of the larynx controls the movement of the nearest part of the tongue to which it is attached. It should be pointed out that none of the EMG studies intends to examine vowels beyond the relatively contained boundaries of normal speech or vowels with strong secondary colouring, so the results are neither as extreme as they would be if the tongue were stuck out of the mouth or if laryngeal constriction were present during [i], [æ], or [u]. To test the laryngeal constrictor hypothesis, instrumental studies would be expected to test primary vocalic values (such as Cardinal Vowel values) against the introduction of secondary vowel colouring having different degrees of auditory prominence.

2.2. Laryngeal physiological actions

To examine the chain-link nature of the interaction of the laryngeal articulator and the oral articulator, the musculature of the larynx needs to be described. Perhaps the most important part of the laryngeal musculature is exactly that aspect which is left out of most phonetic vocal tract diagrams, not to mention most anatomical descriptions of the speech mechanism. It is this aspect of the laryngeal valve system that protects the airway from earliest infancy by means of autonomic reflexive control. It is the aryepiglottic laryngeal constrictor mechanism, defined initially by the superior margins of the arytenoid cartilages, along the aryepiglottic folds and bordering the surface of the epiglottis, and including reflex responses in the tongue and of the larynx itself (Esling 1996, 1999; Gauffin 1977; Lindqvist 1969;



(a) (b) (c)

Figure 3: Three degrees of laryngeal constriction: (a) the larynx in neutral position; (b) partial constriction, with partial aryepiglottic fold sphinctering, moderate larynx raising, and moderate tongue retraction; and (c) almost complete laryngeal constriction, with a narrowed aryepiglottic passage, shortened vocal folds, extreme larynx raising, and extreme tongue retraction.[2]

Williams et al. 1975). One of the best sources for modelling this mechanism is the experimental work on Khoisan languages by Traill (1985, 1986). Its physiological function is pictured in Figure 3, where full engagement of the mechanism (full closure of the valve) results in an epiglottal stop. Its key characteristics are the forward and upward narrowing of the epilaryngeal tube above the glottis, the raising of the larynx, and the retraction of the tongue (to which the epiglottis is attached). Closure occurs as the bent aryepiglottic folds — the active articulator — press up against the surface of the epiglottis — the passive articulator.

A revised phonetic cross-sectional diagram of the vocal tract pictured in Figure 4 divides the vocal tract into oral and laryngeal components, combines pharyngeal and epiglottal categories at the same place of articulation, represents laryngeal constriction as opposite in direction to oral strictures, and separates glottal activity from the laryngeal sphincter at the aryepiglottic folds. Two other parameters essential to the complete phonetic description of speech sounds — pitch control and larynx height — are also represented in the diagram.

[2] In Figures 3, 4, and 6, the following abbreviations are used:

A	arytenoid cartilage	H	hyoid bone
AE	aryepiglottic folds	T	tongue
C	cricoid cartilage	Th	thyroid cartilage
Cu	cuneiform cartilages in epiglottic folds	U	uvula
		Ve	ventricular folds
E	epiglottis	VF	vocal folds
Gl	glottis		

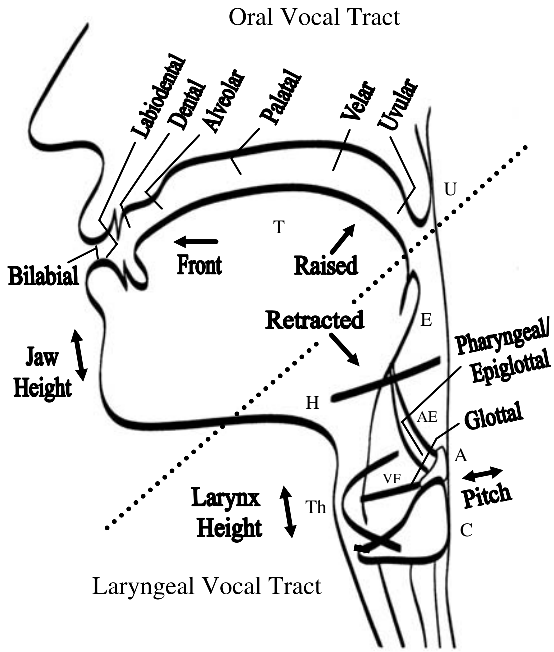


Figure 4: Vocal tract diagram labelled to represent the oral and the laryngeal articulators. The nasal tract is not shown.

2.3. Bridging the laryngeal articulator with the tongue

Front vowels are not raised; they do not have to be. Because of the downward-sloping angle of the hard palate, the alveolar ridge, and the upper teeth at the front of the mouth, tongue fronting accomplishes efficient and rapid filling of this space without the need for the tongue to be lifted or pulled high, as is the case with raised vowels. But it should also be no surprise that articulatory mapping in speech production need not correspond exactly to the auditory/acoustic mapping of the speech output that results. The electromyographic data on vocal tract musculature reported by Baer et al. (1988) show that the posterior genioglossus causes tongue advancement, also forcing the tongue dorsum upward, while contraction of the anterior genioglossus pulls the dorsum forward and down. Harris et al. (1992) indicate strong activity in the genioglossus (both posterior and anterior) muscles for /i/ but little activity (less than 20%) in the styloglossus muscles. Honda's (1996) results show major activity in the posterior (and anterior) genioglossus muscles for /i/ and little if any activity at all in the styloglossus muscles.

The anomaly of the historical gap at the bottom of the vowel chart is explained by this modified view of tongue and larynx interaction. The gap is plain

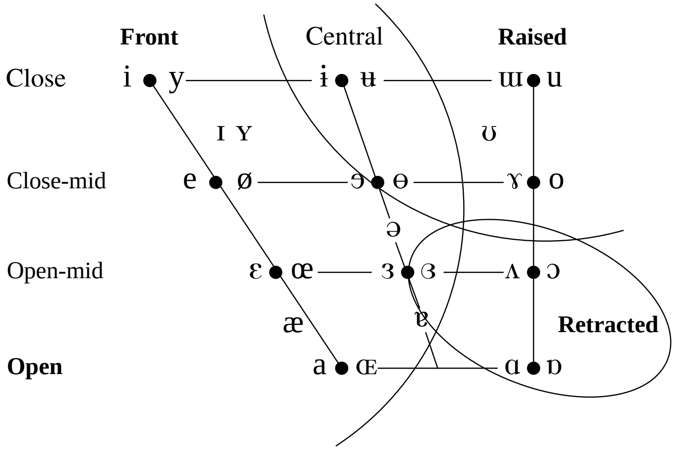


Figure 5: Revised vowel chart showing the division and overlap of articulatory regions.

to see in Figure 2, where there is no vowel quality designated in the space between [a] and [ɑ]. The quality that comes closest to sharing front (open) features with retracted features is [ɐ], which is not regarded as fully open. It is a telling commentary on the development of the International Phonetic Alphabet that a fully open vowel has never been placed between front [a] and back [ɑ], even though there often seems at least superficially to be a need for one in many phonological instances. The logic of a fronting mechanism in articulatory opposition to a retracting mechanism thus seems to have been preserved in the IPA's representation of the auditory phonetic space. This logic can be stated in terms of the presence of a (lingual) fronting articulator, a (mandibular) opening articulator, and a (laryngeal) retracting articulator, but of the absence of an independent lingual lowering articulator. Once *low* has been redefined in this way, it is equally logical to separate raising from fronting as the articulatory realization of high vocal quality. In Figure 5, [ɐ] is represented at the boundary of fronting and retracting. Since no articulator is present that could lower [ɐ] centrally, any further lowering of [ɐ] would result in either a quality that sounds more open and front (because of jaw opening) or a quality that sounds more laryngeally retracted (because of laryngeal constrictor activity). The intersection of the three lines dividing the three regions in Figure 5 should perhaps fall exactly on the location of schwa to represent the focal point of movement away from neutral toward any of the three directions. In this diagram, however, it is first necessary to show the susceptibility of [ɐ] to becoming either front or retracted depending on the choice of articulator movement. Figure 5 also shows the relative predominance of front oral vocal tract features and the relatively greater distance from them of the laryngeally retracted component than if the two regions intersected at schwa.

2.4. Laryngeal logic

Anatomically, it is important to explain that the laryngeal quality of a vowel sound does not necessarily have to be considered a secondary feature to oral vowel quality. Research into the earliest production of speech sounds by infants in the Infant Speech Acquisition Project at the University of Victoria indicates that the larynx and pharynx are the first regions of the vocal tract that infants begin to explore phonetically (Esling et al. 2004). That is, articulatory modalities are first discovered with sounds produced at the *pharyngeal*/*epiglottal* articulator in Figure 4, defined by the aryepiglottic folds. This region is predisposed anatomically for sound production by the infant and represents the beginnings of Phonetic Awareness. Most phonetic production emerging in the earliest months, in fact in the first six months of life, is a function of the laryngeal constrictor. This includes vocoid sounds as well as vocalizations with contoid stricture, and suggests that the laryngeal articulator is explored and employed first before purely oral sounds can be attempted. Non-constricted vocalizations emerge only gradually over the months, appearing in systematic integration with pharyngeal sounds throughout prebabbling and into the babbling stage (Bettany 2004). These earliest vocalizations had been termed “grunts” (McCune et al. 1996; Vihman 1996; McCune and Vihman 2001) but have come to be better understood phonetically since the mechanism of the laryngeal constrictor has been explored and elucidated in experimental phonetic research into the ways laryngeal and pharyngeal articulations are used in various strategically selected adult phonologies.

Along with the pervasiveness of /ɑ/ in phonologies (Maddieson 1984), the key role of retracted articulations in emergent infant phonetic production lends an importance to the pharyngeal vocal tract, which may have been previously overlooked in infant studies. The typical three-vowel system is [i ɑ u]; or it may be described as [i a u]. The peripheral oral vowels [i] and [u] exploit maximally the unrounded-rounded labial adjustment as an inherent component of their quality, while the open vowels are not as strongly affected by labial adjustments. Jaw opening is dominant over labial setting at the front as vowels open, and laryngeal constriction is dominant over labial setting at the back as vowels retract. And just as in adult phonologies, [a] and [ɑ] are more circumscribed than [i] and [u]. For example, in some languages of West Africa, vowel harmony operates on [i, ɪ] and [u, ʊ] (and on [e, ɛ] and [o, ɔ]) differently from the case of the open vowel, which can occur together with either the non-constricted or the constricted series (Gordon 2006). An infant’s alternation between [a] and [ɑ] can be attributed to slight variation in jaw openness or labial setting or laryngeal constriction, where the laryngeal effect plays the dominant role in altering auditory/acoustic quality. The intrinsic anatomical and acquisitional predominance of the laryngeal region can exert a significant qualitative influence on peripherally oral vowels such as [i] and [u] and even [a]. Research into a wide variety of phonetic systems in different language families has produced a convincing picture of how extensive the laryngeal/pharyngeal articulator is in generating phonological contrasts.

3. ARTICULATORY PHONETIC STUDY OF THE LARYNX

For many years, research in the Department of Linguistics at the University of Victoria has focused on indigenous languages of North America, especially Wakashan and Salishan languages. West Coast Vancouver Island Nuu-chah-nulth and Interior BC Salish, in particular, illustrate an impressive range of use of pharyngeal articulations. Using technology developed in Tokyo (Sawashima and Hirose 1968) and phonetic observation procedures developed in Edinburgh (Esling 1984; Williams et al. 1975) and also practised in Paris (Vallancien 1960), over 15 languages have now been studied laryngoscopically at the University of Victoria to determine how various phonetic/phonological descriptors and articulatory gestures coincide. Languages in the video database of the larynx and pharynx thus far include: Nuu-chah-nulth (Wakashan), Nlaka'pamuxcín (Salish), Tigrinya (Semitic), Palestinian Arabic (Semitic), Somali (Cushitic), Amis (Austronesian), Yi (Tibeto-Burman), Bai (Sino-Tibetan/Tibeto-Burman), Tibetan (Tibeto-Burman), Sui (Kam-Daic), Thai (Daic), Pame (Oto-Manguean), Cantonese (Sino-Tibetan), English (whisper studies), Chinese (whisper studies), Korean (Altaic), and Kabiye (Gur).

3.1. Methods and scope

Originally intended to examine what was thought to be purely glottal behaviour (states of the glottis and the phonation type component of voice quality), these visual observation procedures have been extended to describe articulations in the pharynx and refined to incorporate new findings with each language studied (Esling 1996, 2006; Esling et al. 1994). Sounds that have a component made deep in the throat are not easily observed. Therefore, phonetic research using direct visual evidence of the larynx and pharynx has been rare in the literature. Original observations of articulatory production focused on cardinal phonetic "benchmark" categories as outlined in Catford (1964, 1968, 1977) and Laver (1980). Instrumental phonetic equipment consists of a Kay Elemetrics Rhino-laryngeal-stroboscope (RLS 9100) with a constant halogen cold light source, which is the mode used to photograph the actions of the larynx in the pharynx. An Olympus ENF-P3 fibreoptic nasendoscope is attached to the camera (a one-chip Panasonic KS152 and more recently a three-chip Panasonic GP-US522) and to the light source. A 28mm lens is used for optimal wide-angle framing of laryngeal and pharyngeal mechanisms during extreme pharyngeal articulations and of laryngeal postures during the varying pitch conditions of a full tonal paradigm. Earlier recordings were made on a Mitsubishi S-VHS BV-2000 analog video-cassette recorder running at 30 frames/sec, and later recordings were made directly on a Sony DCRTRV17

Mini-DV Digital Camcorder. Video images were post-processed with Adobe Premiere 6.5 software. The cardinal benchmark parameters, or canonical profiles, then served as a basis of comparison with the production of phonological items by native-speaker subjects.

3.2. Canonical profiles of glottal and pharyngeal categories of articulation

Initial phonetic findings had a direct bearing on how the mechanism of the larynx and the states of the glottis and phonation types are understood (Esling 1996). A number of conclusions emerged:

a. In pharyngeal sounds, the arytenoid cartilages move forward and up under the epiglottis and the tongue. Rather than the epiglottis serving as a flap that covers the airway, the arytenoid system acts as the main articulator, working in reverse, as it were, against the tongue, to block the flow of air.

b. The pharyngeal articulator (i.e., the mechanism that produces [ħ] and [ʕ] and pharyngealized sounds) is essentially aryepiglottic. The arytenoid cartilages, the corniculate cartilages at their apices, the aryepiglottic folds that bend forward at the cuneiform cartilages, and the attachments of the aryepiglottic folds at the margins of the epiglottis constitute the upper borders of the supraglottic tube that sphincters shut to compact the volume of the pharynx.

c. Pharyngeal sounds involve retraction of the tongue and raising of the larynx for efficient laryngeal sphinctering. Both conditions are unmarked in laryngeal constriction. Because the muscle groups are linked across the hyoid bone, their contraction both pulls the tongue down and back and pulls the larynx up and forward as the aryepiglottic folds compress. This chain of events means that the stricture for pharyngealization is equivalent to the stricture that produces the voice quality types *pharyngealized voice* at low pitch and *raised larynx voice* at high pitch (Esling et al. 1994).

d. Full closure of the airway occurs at the aryepiglottic location (the laryngeal constrictor), that is, epiglottal stop [ʡ] is produced at the pharyngeal place of articulation. This means that the primary articulatory actions occurring in the pharynx and controlling the shape of the pharynx are laryngeal.

e. The tongue may retract pharyngeally, but only after the laryngeal constrictor has been engaged. In other words, pharyngeals are not a function of independent movement of the tongue in the same way that uvulars, velars, or dentals are. The laryngeal constrictor is a buckling mechanism, and at a certain point in its engagement, the tongue retracts to complete the action of reverse closure over the airway.

f. Trilling of the aryepiglottic folds enhances pharyngeals to produce sounds that have been identified as epiglottal [ʜ ʢ]. Once compression of the constrictor mechanism is tight enough, the aryepiglottic folds can trill against

Table 1: Glottal/pharyngeal consonantal distinctions in the laryngeal model

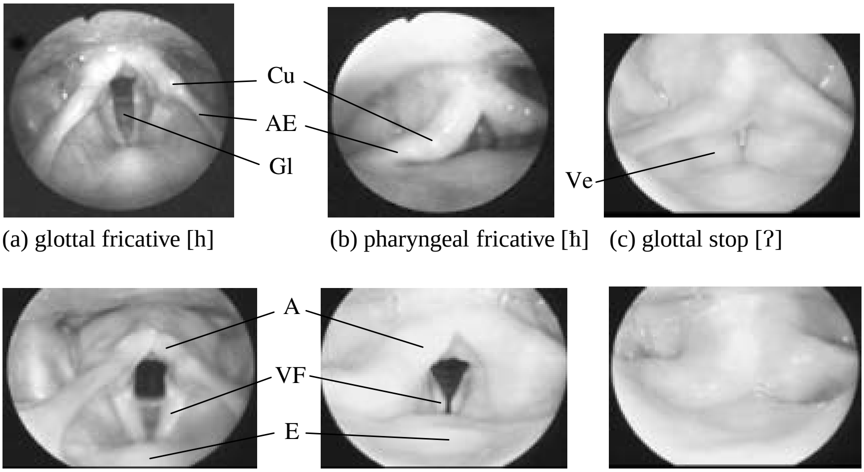
Glottals		Pharyngeals (epiglottals)	
[h]	Voiceless glottal fricative	[ħ]	Voiceless pharyngeal fricative
		[ʜ]	Voiceless epiglottal fricative (with aryepiglottic trilling)
		[ʕ]	Voiced pharyngeal approximant
		[ʢ]	Voiced epiglottal fricative (with aryepiglottic trilling)
[ʔ]	Glottal stop	[ʡ]	Epiglottal (pharyngeal) stop

the epiglottal surface. This trilling can be accompanied by glottal voicelessness or voicing. In this case, it is the active articulator that trills — analogous to the tongue trilling against the alveolar ridge in the oral cavity — although a passive articulator can also trill, as is the case with the uvula in a uvular trill. If the place of articulation is the same for pharyngeals and epiglottals, then epiglottals can be regarded in this interpretation as "enhanced fricatives", just as uvular fricatives can be enhanced by trilling of the uvula. These are all phonetic options that a phonology can choose in order to represent distinctiveness.

g. Larynx raising may also account for epiglottal [ʜ ʢ]. In phonologies that have been reported to contrast pharyngeals and epiglottals, if /ʜ ʢ/ are not enhanced fricatives, then they are most likely to exhibit the unmarked raised larynx of laryngeal constriction, while /ħ ʕ/ would have lowered larynx and the consequent lower-pitched resonances of an expanded pharynx.

Thus, in the laryngeal model, expanded pharynx is largely a function of lowering the larynx — opposite to the action of the laryngeal constrictor to raise the larynx and reduce the size of the pharynx in an upward direction. Several glottal/pharyngeal consonantal distinctions can be reinterpreted in the light of this redefinition of the pharyngeal articulatory space. Table 1 illustrates the array of pharyngeal/epiglottal categories that contrast with glottal categories. These articulatory interpretations fill out the pharyngeal place of articulation on the 1996 IPA Consonant Chart (IPA 1999:ix) with the same set of manners of articulation that characterize the uvular place of articulation, with the exception of nasal. All of these articulations may be produced with a raised larynx or a lowered larynx, with mixed consequences for the resulting auditory quality because of certain inherent entailments of the mechanism.

Figure 6 portrays some cardinally distinct snapshots of laryngeal posture. All but one are voiceless. Figure 6a is the cardinal state of breath, which is the configuration for an [h] or a voiceless fricative. Its key characteristic is that the supraglottic tube of the lower pharynx — between the aryepiglottic folds and the



(a) glottal fricative [h] (b) pharyngeal fricative [ħ] (c) glottal stop [ʔ]

(d) breathy voice phonation [ɦ] (e) whisper (f) epiglottal stop [ʡ]

Figure 6: Six articulatory postures of the laryngeal articulator.[3]

epiglottis — is wide open, just as the vocal folds are parted at the glottis for voicelessness. These same postures characterize breathy voice ([ɦ]) in Figure 6d, which differs from Figure 6a only in that the arytenoids are slightly more adducted (for voicing) and the vocal folds are vibrating at the anterior end of the glottis.

The laryngeal postures for [h] and [ɦ] have no particular effect on the tongue, unless the larynx is substantially elevated at the same time. Normally, they predispose laryngeal lowering, which coincides unmarkedly with opening of the glottis and of the laryngeal constrictor (Esling 1999). Figure 6b shows what happens when the laryngeal constrictor engages. With the glottis still open, the arytenoids are pulled upward and forward so that the cuneiform tubercles of the aryepiglottic folds approach the surface of the epiglottis. Here, the aryepiglottic folds are the active articulator, and the epiglottis is the passive articulator; so the label *epiglottal* would be an appropriate designation. With glottal voicing, this same configuration would yield the pharyngeal (epiglottal) approximant [ʕ]. Both voiceless [ħ] and voiced [ʕ] could be enhanced by the addition of aryepiglottic trilling, which creates one possible distinction between pharyngeal [ħ ʕ] and epiglottal [ʜ ʢ]. Normally, the constricted posture is accompanied by larynx raising, which coincides unmarkedly with the closing off of the airway.

The voiceless pharyngeal fricative is virtually the same as the posture for whisper in Figure 6e. The whispered state of the glottis has now been studied in detail in Arabic, where /ħ ʕ/ occur, demonstrating that whisper entails stricture of the laryngeal constrictor mechanism (Zeroual et al. 2005). When this constrictive gesture occurs, the tongue is likely to be retracted as a consequence. The

[3] In Figures 6d and 6e, “A” refers to the corniculate tubercles of the arytenoid cartilages.

degree of laryngeal elevation seen in Figure 6e would certainly entail greater tongue retraction than required for [ɑ].

The remaining two states are also a function of the laryngeal constrictor mechanism. Figure 6c, glottal stop [ʔ], requires adduction of the arytenoids and the vocal folds at the glottis and just enough constrictive compression to bring the ventricular folds together over the glottis to arrest vocal fold vibration or the possibility of voiceless airflow (Esling and Harris 2005). In Figure 6f, the aryepiglottic folds are pressed tightly up against the surface of the epiglottis, entailing significant larynx raising and tongue retraction. It is possible to perform an epiglottal stop with lowered larynx, but such a posture is relatively inefficient physiologically, drawing the laryngeal structures away from the retracted tongue, but tongue retraction cannot in any case be avoided when the aryepiglottic borders are tightly sphinctered. Tongue retraction is the physiologically entailed consequence of forceful airway closure and thus presumably the unmarked condition in the phonological implementation of the laryngeal constrictor, shutting completely the supraglottic tube of the lower pharynx and significantly reducing the remaining volume of the pharynx.

3.3. Glottal and pharyngeal articulations in Pacific Northwest languages

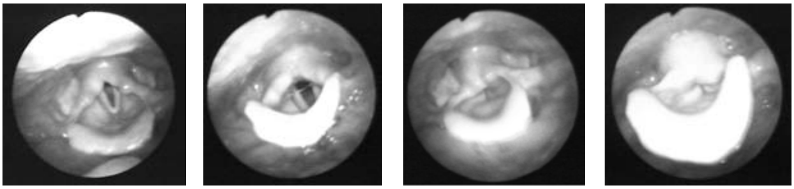
The Pacific Northwest is a region of different language families with outwardly similar phonological inventories. The goal of phonetic research has been to study in detail the articulations of sounds in the lower vocal tract using audio recordings and digital laryngoscopic images. The Nuu-chah-nulth (Nootka) dialects of Wakashan (e.g., Ahousaht) and the Nlaka'pamuxcín, Nxa'amxcín, and Npoqínišcn/Qalispé varieties of Salish have all been found to close the larynx completely for the speech sound "epiglottal stop" (Carlson and Esling 2000, 2003; Carlson et al. 2001; Czaykowska-Higgins and Kinkade 1998). To account for the phonetic behaviour observed in these languages, the pharynx is classified as part of the laryngeal articulator (rather than lingual) because the laryngeal constrictor mechanism (controlling changes from the glottis to the aryepiglottic folds) is the principal articulator whose movements determine the shape of the pharynx. With the airway optimally shut, the pharynx is small; the aryepiglottic folds are pressed against the epiglottic tubercle, the tongue is retracted, and the larynx is raised. In addition to the glottal fricative and glottal stop, these languages also contain either a pharyngeal fricative or approximant (at the same place of articulation as epiglottal stop but with less stricture) and, in Nlaka'pamuxcín, some uvulars are also pharyngealized (with less stricture again than the pharyngeal approximant). Pharyngeal resonance in all these cases is dependent initially on the shortening of the supraglottic tube and subsequently on the combined effect of tongue retraction and larynx raising reducing the volume immediately above the supraglottic tube. The inventories of Nuu-chah-nulth and of Nlaka'pamuxcín are shown in (1).

(1) *Inventories of Nuu-chah-nulth and Nlaka’pamuxcín*:

Nuu-chah-nulth (Wakashan)						Nlaka’pamuxcín (Salish)					
Bilabial	p	p’		m	**^{ʔ}m**	Bilabial	p	p’		m	**m^{ʔ}**
Denti-alveolar	t	t’				Alveolar	t	t’		n	**n^{ʔ}**
	ts	ts’	s				ts	ts’	s	z	**z^{ʔ}**
Apico-alveolar	tɬ	tɬ’	ɬ	n	**^{ʔ}n**			tɬ’	ɬ	l	**l^{ʔ}**
Postalveolar	tʃ	tʃ’	ʃ			Postalveolar	tʃ		ʃ		
Palatal				j	**^{ʔ}j**	Palatal				j	**j^{ʔ}**
Velar	k	k’	x	w	**^{ʔ}w**	Velar	k	k’	x	(ɣ)	**(ɣ^{ʔ})**
	k^{w}	k^{w}’	x^{w}				k^{w}	k^{w}’	x^{w}	w	**w^{ʔ}**
Uvular	q		(χ)			Uvular	q	q’	χ		
	q^{w}		(χ^{w})				q^{w}	q^{w}’	χ^{w}		
Pharyngeal			**ħ**	ʕ		Pharyngeal				**ʕ**	**ʕ’**
										ʕ^{w}	**ʕ^{w}’**
Glottal	ʔ		**h**			Glottal	ʔ		**h**		

The properties of the glottal, pharyngeal, and glottalized sounds (in bold in (1)) of Nuu-chah-nulth are described extensively in Esling (2003a) and Esling et al. (2005), and those of Nlaka’pamuxcín in Carlson et al. (2004). The glottals correspond very closely to their canonical profiles. While [h] is open at the level of the supraglottic tube (the laryngeal constrictor), [ʔ] shows enough tension in the aryepiglottic mechanism to purse the sphincter so that the ventricular folds close in on the vocal folds to stop them vibrating (2). It is not clear whether much tongue retraction, if any, is required to achieve this slight degree of inferior, medial laryngeal constriction. Glottalized resonants in Nuu-chah-nulth are preceded by [ʔ] — the same gesture and lasting an identical length of time as phonemic /ʔ/. Glottalized resonants in Nlaka’pamuxcín are followed by [ʔ] — as in phonemic /ʔ/ — with attendant laryngealization (creaky voice) and typically voiceless release. In both cases, this means that the glottalized resonants are about twice as long as their corresponding non-glottalized resonants. The interesting articulatory extension in Nuu-chah-nulth to these glottal, glottalized, or glottalized-laryngealized phenomena is the pharyngeals, which last longer as articulatory events and engage the laryngeal constrictor to its fullest degree. The phoneme represented as /ʕ/ is in fact an epiglottal stop [ʡ], with full closure at the aryepiglottic sphincter. Its approximant offglide [^{ʕ}] is perhaps a natural phonetic consequence of its length. Voiceless /ħ/ is a pharyngeal fricative, with a similar engagement of the sphincter and long offglide, except that the glottis remains parted (as it does for [h]). Both sounds entail radical retraction of the tongue as the aryepiglottic mechanism rises up and forward to restrict the airway. Retraction is so great that for [ħ], none of the constrictor mechanism beneath the retracted tongue and epiglottis can be seen from above. Although the tongue is usually more retracted for Nuu-chah-nulth [ʡ], the view in (3) captures a momentary glimpse of full aryepiglotto-epiglottal stricture. These consonants have been shown to have a significant retracting effect on neighbouring vowels (Wilson, to appear).

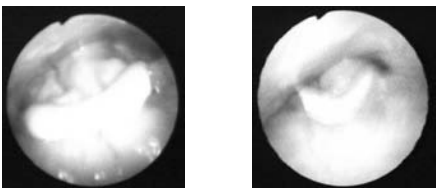
(2) *Laryngoscopic view of pharynx/larynx: glottal articulation of* [h] *(no constriction) and* [ʔ] *(slight constriction)*:



Nuu-chah-nulth [h]	Nlaka’pamux [h]	Nuu-chah-nulth [ʔ]	Nlaka’pamux [ʔ]
/himwits’a/	/mijˀt/ [mḭjˀə̥tʰ]	/ʔiːħ/	/mijˀt/ [mḭjˀə̥tʰ]
‘story’	‘spreading disease’	‘big’	‘spreading disease’

The plain pharyngeal in Nlaka’pamuxcín is an approximant [ʕ], which also induces significant tongue retraction and is difficult to distinguish visually from full closure, viewed from above. It is the so-called glottalized pharyngeals that are in fact epiglottal stops [ʡ] and [ʡʷ], with full closure at the aryepiglottic sphincter and the voiceless release typical of these Salish languages. Some uvulars in this variety have significant pharyngealization, which implies that they are not only raised (to be uvular) but also retracted (since pharyngealization is a function of the laryngeal constrictor). The co-articulatory effect of pharyngeals in these languages should be viewed in conjunction with the inherent retracted potential of an [ɑ] vowel, although retracting can affect any other vowel.

(3) *Aryepiglotto-epiglottal articulation of epiglottal stop* [ʡ] *(full constriction)*:



Nuu-chah-nulth [ʡ]	Nlaka’pamux [ʡ]
/ʕiħuː/ [ʡˤɪħˤuː]	/npaʕʷ’/ [nːˈpaˤʡʷ̥]
‘to cry after’	‘ice’

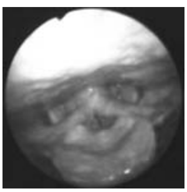
3.4. Register distinctions in Tibeto-Burman languages

In the Pacific Northwest languages, the implementation of the laryngeal articulator is primarily consonantal, and the effect on vowels is co-articulatory. There are other languages that do not have pharyngeal consonants per se, but which use the laryngeal constrictor mechanism to alter the shape of the pharynx to generate distinctive vowel quality or phonatory quality. A contrastive tonal register system exists in Bai, a Tibeto-Burman language (possibly Sinitic, in some views) of Yúnnán Province in southwest China (Edmondson and Li 1994; Li 1992). There are five tones in Jiànchuān Bai with accompanying shifts in phonatory quality and in constrictor tension, which together with a nasality contrast yield 15 contrastive syllable types. The articulatory phonetic challenge was to determine instrumentally how tone (pitch) interacts with laryngeal constrictor adjustments to produce differences at the glottis at the same time as differences at the level of the supraglottic tube. A contrastive vowel quality series exists in Yi, a Tibeto-Burman language of Sìchuān Province in southwest China (Chen 1988; Lama 1998). This variety has a five-pair vowel set, each with a lax and a tense counterpart. The articulatory phonetic challenge was to determine instrumentally how the tense vowels are produced differently from the lax vowels.

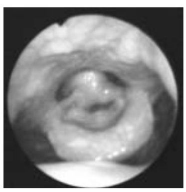
3.4.1. Bai tonal registers

The images of two words in Bai (4) illustrate the laryngeal paradigm particularly well. As discussed in section 3.2, opening the glottis and lowering the larynx are physiologically compatible activities and do not entail tongue retraction, while closing off the airway is compatible with raising the larynx and does entail tongue retraction reciprocally. At the mid-pitch level in the Bai tonal paradigm, the register paradigm produces a contrast between a phonation type that is breathy and a phonation type that is harsh. As in Yi, these contrasting phonatory possibilities have been named *lax* and *tense*. The lax token is not only breathy (at the glottis) but also open in the lower pharynx because (a) the laryngeal constrictor is inactive; (b) the tongue is not retracted; (c) the pitch level is low enough that the glottis can easily part to produce breath, but not so low that the constrictor would begin to be actively engaged; and (d) the larynx itself remains low. The tense token is harsh (as a function of the phases of vibration), and the pharynx is shortened as well as reduced in volume at the level of the supraglottic tube at its base because (a) the laryngeal constrictor is actively engaged; (b) the tongue is retracted; (c) the pitch level is systematically elevated so that, combined with constriction, the glottis is not relaxed but under both longitudinal and constrictive tension so it can produce harshness; and (d) the larynx itself is elevated.

(4) *Bai breathy lax mid tone versus harsh tense mid tone*:[4]



[tɕĩ̠̤^{31}] ‘alkaline’



[tɕĩ̠̰^{42}] ‘arrow’

The images shown in (4) are taken from approximately the mid-point of the vowel in each syllable. Several other phenomena that the laryngeal articulator model

[4] Superscript numbers indicate tones.

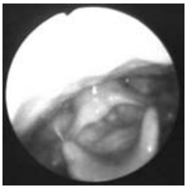
accounts for particularly well occur in Bai, including aryepiglottic trilling at very low pitch and constriction together with vocal fold stretching at very high pitch, but these do not of themselves have as clear an influence on vowel quality as the parallel series in some other languages. A full discussion of the laryngeal study of Bai can be found in Edmondson et al. (2001).

Both tokens are drawn from the nasal series, but that is independent of the laryngeal paradigm. Lax [tɕĩ̤^{31}] ‘alkaline’ results in a pharyngeal resonator that has not been shortened and remains large. Tense [tɕḭ̃^{42}] ‘arrow’ results in a pharyngeal resonator that is shortened, pursed at the bottom, and has a smaller volume. It is the acoustic characteristics of the resonating cavity that will have a bearing on the resulting vowel quality. In Bai, however, unlike Yi, the changing qualities of the vowels from lax to tense are not as noticeable, presumably because the effect of constriction on the laryngeal sound source (in altering tone and phonation type) is so much greater. Also, the quality of an oral vowel does not necessarily have to sound like another (more retracted) vowel when the laryngeal constrictor is engaged; it could, through articulatory compensation, sound like the same vowel, but its quality will inevitably sound pharyngealized (having an auditory colouring that represents a reduced pharyngeal volume). In Bai register tones, the effect of constriction on phonation and pitch is a dramatic auditory cue. The effect on the quality of vocalic resonance is more subtle, but it can be observed in the spectral formant frequencies of contrasting syllables (Esling and Edmondson 2002).

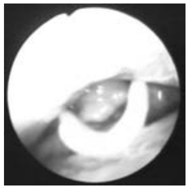
3.4.2. Yi register and vowel shift

In the case of Yi, the effect of constriction on the laryngeal sound source (in altering tone and phonation type) is negligible. Both the lax series and the tense series are generally produced with modal phonation. The major auditory/acoustic effect is in the quality of the vowels as produced with the two contrasting resonating cavity shapes. There are three (perhaps four) tones, but the most common is the mid tone (^{33}); and the higher and lower tones variably restrict the occurrence of the two registers. The five vowels in the lax register are [i z ɯ o v], two of which are fricativized. They are all relatively peripheral in their oral location (in the range between front and raised, in terms of the tongue). The five corresponding vowels in the tense register are [ɛ̱ ẕ a̱ ɔ̱ v̱], which are all lowered, in traditional terminology, from the lax vowels (e.g., [i] to [ɛ̱], and [o] to [ɔ̱]). There is, however, a common thread that typifies the articulatory production of all the tense vowels, represented here by the retracting diacritic under the vowel. The representational issue is whether the retracting diacritic means that the tongue is “backed” (as it would in the H-L-F-B model) or whether another generalizable articulatory phenomenon characterizes all five vowels uniformly. The problem with the backing interpretation is that the tense vowels are not uniformly backed or lowered, and that the direction and dimension of shift in the auditory vowel space is not the same for each vowel.

(5) *Yi non-constricted lax register versus constricted tense register*:



/pv^{33}/ ‘river deer’



/pv̲^{33}/ ‘to go back’

Laryngoscopic examinations show that the tense vowels are produced uniformly differently from the lax vowels as a function of the degree of closing in the laryngeal constrictor, as shown for the /v v̲/ contrast in (5). In the first image (of the labiodentalized [v͡ʊː] vowel), the epilaryngeal space is open, the tongue is not retracted, and the larynx is not raised. In the second image (of the labiodentalized and constricted [v̙͡ʊ̙ː] vowel), the larynx has moved upward, closer to the endoscope, and the laryngeal/pharyngeal structures (here the arytenoids and the epiglottis) have become larger and more reflective in the fibreoptically transmitted light. This is the same mechanism that operates to produce consonantal pharyngeal articulations in the Pacific Northwest languages. If the posture for the tense vowels in Yi were a consonant phonologically, it would be a voiced pharyngeal approximant. Since the constriction occurs on a vocalic sound in Yi, however, its duration is longer, and its effect is to add secondary colouring to the resonance that results from both the posture of the laryngeal vocal tract and of the oral vocal tract. Each sound is therefore perceived as a vowel, but it is more economical to consider all of the tense vowels as constricted laryngeally, and therefore retracted lingually. The lingual retraction interpretation does account for what the tongue is doing in Yi, but only if taken together with a description of how the primary structures of the larynx are changing the shape of the pharynx. The two actions are complementary to each other, not separate. The lax vowels can therefore be considered non-constricted as well as complementarily non-retracted. Tense vowels also induce other effects in the syllable that are not lingual. Phonetically, the contrast can be transcribed narrowly as [pv͡ʊ̝ː^{33}] versus [pʙɵ̙ː^{33}]. Beyond the difference in vowel quality and in the degree of laryngeal stricture shaping the pharynx, there is also a labial enhancement in the tense context. The phonetic system of Yi is discussed in detail in Esling and Edmondson (2002).

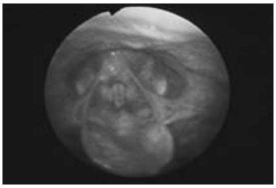
Although the tense vowels also differ in oral quality from the lax set in Yi, it is important phonetically that tongue retraction at the back as well as jaw opening at the front are compatibly predictable consequences of the engagement of the laryngeal constrictor. The laryngeal articulator model captures this generalization elegantly. Instead of describing vowel quality solely as an oral phenomenon and attributing tension in the vocal tract to some generalized tightening of the musculature, the laryngeal articulator model first describes the posture of the laryngeal/pharyngeal articulator (most simply as constricted versus non-constricted) and then relates oral phenomena to it by means of the four dimensions of oral movement: retracted, raised, front, open. It is significant to note here that the tense-lax distinction described for the Tibeto-Burman languages is not the same as the tense-lax distinction described for Germanic languages (Jakobson and Halle 1964). Whereas Germanic tense-lax differences are probably best explained prosodically (Murray 2000), tense-lax in the Tibeto-Burman context can best be explained as constricted versus non-constricted, with the consequent lingual effects of those settings. Lingual retracting is a property of the tense series in Tibeto-Burman languages because the tense series is constricted. In Germanic languages, lingual retracting would be ascribed to the lax series and described as −ATR because those vowels are lower or further back. The contradiction here, which is at least terminological and at worst conceptual, lies in a misinterpretation of the entailments of the laryngeal constrictor mechanism. Physiologically, vowels that are more retracted are demonstrating a lingual reflex of constriction in the laryngeal mechanism. If Germanic lax vowels are in fact shown to demonstrate the articulatory characteristics of laryngeal constriction in conjunction with their lingual properties, then they should logically be called tense to reflect the tension that is present in the larynx/pharynx. That is, lax vowels that have constriction would no longer be lax. The implication is that tension in the tense vowels of Germanic comes from somewhere (or something) else; and therefore syllabic/prosodic characteristics are a more likely differentiator than the intrinsic phonetic properties (laryngeal and lingual) of the vowel itself. Taking the laryngeal articulator starting point, tense-lax is a phonetically optimal definition of the distinction as it is found in the Tibeto-Burman context.

3.5. Somali

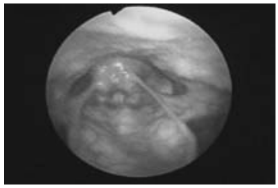
Somali, a Cushitic language, has pharyngeal consonants as in neighbouring Semitic languages such as Arabic and Tigrinya, but it also has a register contrast involving the laryngeal constrictor, which has an effect on both phonation type and on pharyngeal resonance. In this respect, the phonetic use of the laryngeal constrictor mechanism in Somali resembles its operation in Bai and Yi. The two primary registers could be characterized most economically as lowered larynx and raised larynx, following Laver's (1980) terminology for voice quality, or as open versus closed (as descriptors of the laryngeal/pharyngeal space — not of the oral cavity). This corresponds to lax and tense as used in Bai or Yi. The phonation type correlates of the two sets are generally breathy phonation versus harsh phonation, although the register paradigm interacts with tone in complex ways (see Edmondson et al., submitted). The pair of words in (6) shows the contrast as it affects the larynx and lower pharynx in identical consonantal and tonal contexts.

The two vowel sets in Somali can be called non-constricted and constricted phonetically, or lax and tense phonologically. Tension thus has three inherent phonetic correlates by virtue of the definition of the laryngeal constrictor. The aryepiglottic sphincter mechanism is pursed supraglottically, which has an effect on the type of voicing that the vocal folds will produce as a phonation type.

(6) *Somali non-constricted lax register versus constricted tense register*:



[ˈd̥íìʔ͜t] ‘to refuse’



[ˈd̥íì̠ʔ͜t] ‘to faint’

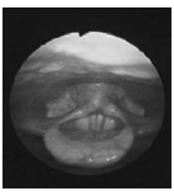
The tongue is at least slightly retracted as a complementary lingual response to constriction. And the larynx itself is raised slightly into the pharyngeal space, reducing the size of the resonating cavity. All these effects appear in the vowel of the word [ˈd̥íì̠ʔ͜t] ‘to faint’, where the structures are compacted postero-anteriorly and are elevated nearer to the camera. Spectral characteristics of the acoustic formants of the constricted vowels conform to the description of *retracted* — they all shift toward the lower-right corner of the vowel space relative to their corresponding non-constricted vowels (Edmondson et al., submitted). There are five vowels, each of which can be short or long. The length distinction introduces some complexity into the system, particularly at the open end, but the dominant difference between vowel types remains their laryngeal classification. The differences cannot be explained in terms of high, low, or back vowel quality alone without reference to the laryngeal category that (a) alters the pharyngeal space in parallel to the oral space, and (b) bears a direct markedness relationship to the oral character of the vowels.

3.6. Kabiye

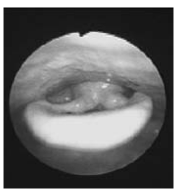
A striking example of the effect that altering the setting of the laryngeal constrictor has on vowel quality is the phenomenon of what has been called the ATR/−ATR contrast (Halle and Stevens 1969). The objective in studying Kabiye was to determine whether the laryngeal constrictor mechanism, and not just the tongue, plays a major role in the contrast between the two vowel series. Unlike Yi or Somali, Kabiye, a Gur language of northern Togo, has five basic vowel qualities that contrast in length, but only four of which contrast phonologically in register; the /a/ vowel can occur in harmony with either register set. The major question to address is to explain how the two registers differ from each other articulatorily, which can be done using the laryngeal articulator model as for the other languages described here. The secondary issue that this state of affairs provokes — the basic question of “what is the /a/ vowel?” — can also be addressed by invoking the laryngeal articulator model.

Instrumental (cineradiographic and MRI) studies of Akan (Lindau 1978; Tiede 1996) show that the set of vowels labelled [−ATR] has a reduced pharyngeal space relative to the [+ATR] vowels. The principal articulator, as these labels imply, is assumed to be the tongue acting on the size of the pharyngeal cavity, but the relationship between the tongue root and the observed correlate of larynx raising is not explicitly explained, although a difference is observed between the behaviour in the height of the tongue and in what makes the pharynx change its shape: “the tongue root in this type of language is independent of the mechanism for controlling tongue height” (Lindau 1978:551). In the context of the laryngeal articulator model, this conclusion reinforces the separation between the oral articulator and the laryngeal articulator, where the [i ɪ, e ɛ, o ɔ, u ʊ] contrasts can be very similar in tongue height (i.e., fronting and/or raising) or not, as the particular language chooses. The contrast between the vowel pairs in the state of the laryngeal articulator, however, is dramatically different in the laryngoscopic images in (7). All the features associated with the use of the laryngeal constrictor in the other languages above are at work in the case of [tʊ̠́]: aryepiglottic sphinctering, tongue retraction, and larynx raising. The proposed term “expanded (pharynx)” to describe [+ATR] vowels (Lindau 1978:552) is a characterization of how the pharynx behaves in the non-constricted context of larynx lowering. The term “constricted (pharynx)”, observed by Lindau to be the opposite of expanded (pharynx), is probably a better label for describing the contrast, since constriction is the primary active phonetic phenomenon of the larynx. It involves not just the tongue root, larynx raising, and possibly a narrowing effect on the pharyngeal walls, but also and primarily the narrowing of the airway at its central point — a central aryepiglotto-epiglottal stricture with concomitant effects and consequent reduction in the size of the pharynx. Most importantly, it is essentially laryngeal, not originally pharyngeal, and it leads and determines what the tongue root does. As inferred from the cineradiographic data, the mechanism for pharyngeal control is separate from the control of the tongue for oral adjustments, and this distinction is fundamental in the separation of the vowel space in Figure 5. The feature [±sphincter] was proposed to account economically for the entire complex of articulatory events (Esling 2003b), but [±constricted] is a more globally adequate feature that incorporates all laryngeal constrictor events.

(7) *Kabiye non-constricted register versus constricted register*:



[tú] ‘elephant’



[tʊ̠́] ‘bee’

The [±ATR] vowels observed laryngoscopically therefore mirror the laryngeal/pharyngeal contrast found in the Yi articulations. The Kabiye [−ATR] vowels and the Yi tense vowels both exhibit systematic aryepiglottic narrowing of the laryngeal sphincter, tongue retraction, and larynx raising. The Kabiye [+ATR] vowels and the Yi lax vowels do not show these effects but have an open epilaryngeal tube. As mentioned above, it can be difficult to know whether the quality of an open vowel should be attributed to lingual characteristics of the oral vocal tract or whether subtle differences within the pharyngeal resonating cavity are imparting characteristics to vowel quality that make it sound differently coloured from another vowel with ostensibly the same oral shape. Both options are available, and West African languages like Kabiye or Akan use both to distinguish their vowel sets. In varieties of Akan where open vowels fall into contrasting registers, their phonetic quality is described as [a] versus [ʌ]. The latter fits the prediction of a retracted vowel in the constricted context. For Kabiye, where research is needed to determine how the single /a/ vowel participates in vowel harmony, the hypothesis drawn from the laryngeal articulator model is that subtle harmonic influences will make /a/ non-constricted in an [i e o u] context but more constricted (toward [ʌ] or [ɑ]) in a constricted [ɪ ɛ ɔ ʊ] context. Whether or not vowel quality alters so that a different oral value is perceived in the vowel, the quality of resonances governed by the laryngeal articulator should pervade the sound.

4. Anatomical Relationships

There are good indications that the thyroarytenoid, aryepiglottic, thyroepiglottic, hyoglossus, and hyothyroid muscles participate in the buckling manoeuvre of the laryngeal constrictor. The description of the anatomy of the thyroarytenoid muscle groups in Zemlin (1998:128–129) gives a good indication of why this should be so. It has long been recognized that the thyroarytenoid muscles can both shorten (relax) the vocal folds, decreasing pitch, and tighten (tense) the vocal folds, increasing pitch (Hardcastle 1976:83). This apparently paradoxical situation can be explained by the laryngeal articulator model. The thyroarytenoid is a multipartite muscle. The internal thyrovocalis runs within the vocal folds themselves, while the thyromuscularis (or external thyroarytenoid) connects the remaining space between the thyroid and the arytenoids. The thyroarytenoid courses anteroposteriorly, which means that when it contracts, it pulls the posterior structures anteriorly (toward its origin). It has lateral fibres that course vertically up into the aryepiglottic fold and also to the lateral margin of the epiglottis becoming the thyroepiglottic muscle (Zemlin 1998:129). This complex configuration of muscle, fanning out posteriorly and upward behind the epiglottis, into the aryepiglottic folds and the arytenoids, is the most likely candidate to be responsible for the first phases of the laryngeal constriction manoeuvre.

The muscle for retracting the tongue, the hyoglossus, is the next likely candidate to be responsible for engaging the participation of the tongue in constriction. It originates in the hyoid bone and inserts into the tongue, pulling the tongue posteriorly and downward (and pulling the hyoid bone up if it is not otherwise stabilized). The suprahyoid muscles are responsible for elevating the larynx as the supraglottic cartilages, folds, and tube compress against the underside of the tongue and epiglottis. As the x-rays in Traill (1985, 1986) show, all the involved structures, from the tongue to the laryngeal cartilages, compress together around the hyoid bone when the laryngeal constrictor engages (for sphincteric aryepiglottic trilled phonation in the case of !Xóõ). At the glottis, this action predisposes low-pitched vocal fold vibration, including creaky voice, because it shortens the vocal folds by compressing the distance from back to front immediately over the glottis. At the same time, this action introduces the possibility of tension, rather than relaxation, because it is the mechanism for full compression of the airway, increasingly restricting the ease with which air can pass through the glottis and the supraglottic tube. The auditory correlates of voices produced in this mode have been shown to be regarded as tense and even threatening (Teshigawara 2003; Teshigawara and Murano 2004). It should be reiterated that pitch does not have to be low when the constrictor is engaged. Although low pitch is usually the likely outcome of contracting these muscles, the cricothyroid muscles can also be contracted at the same time, stretching the vocal folds while the constrictor is engaged, producing harsh (tight/tense) phonation at high pitch. This possibility has been described in detail as one category of harsh voice in Esling and Harris (2005). Aside from the direct effect on vocal fold vibration, if the thyroarytenoid within the larynx is viewed as the engine of the pharynx, then the various postures that the laryngeal constrictor mechanism assumes should be able to be correlated with their effect on the auditory/acoustic output. The laryngeal articulator model thus forms a basis for new hypotheses of acoustic analysis.

To establish articulatory parameters for acoustic modelling, it will be useful to review how the action of the laryngeal constrictor (which drives pharyngealization, laryngealization, glottalization, and whispery, creaky, and harsh modes of phonation) differs from simple tongue backing:

a. With the arytenoids together for voicing or abducted for breath at the glottis, the glottis can also be stretched by means of the cricothyroid muscles to increase pitch. These are the three glottal components of the laryngeal mechanism.

b. If the arytenoids are adducted and the parts of the thyroarytenoid that join with the lateral cricoarytenoid (adductor) muscles then contract, the glottis is compressed from above and closes from front to back as the ventricular folds press down on the vocal folds to arrest vibration and stop air flow.

c. The aryepiglottic folds are brought further forward at their cuneiform cartilages, pursing the supraglottic sphincter from back to front.

d. This has an effect on the quality of voicing if voicing resumes or on the quality of airflow turbulence if voiceless flow resumes.

e. As the aryepiglottic folds at the cuneiform tubercles approximate the epiglottis in a forward and upward motion, the tongue retracts.

f. To assist sphinctering and tongue retraction, the suprahyoid muscles raise the larynx (minimally the hyothyroid muscles in chain-link opposition to the hyoglossus), although it is also possible to voluntarily lower the larynx when the aryepiglottic and lingual parts of the constrictor are engaged.

g. Increased airflow velocity can produce trilling of the aryepiglottic folds, and the tongue presumably has to be sufficiently retracted and the larynx sufficiently raised to produce the narrow approximation of articulators to permit this.

h. Strong contraction of the constrictor complex can cause the palate to lower (through the link to the palatoglossus muscles) and the jaw to open (through the voluntary co-option of the anterior digastric muscles).

i. The actions in steps (c), (e), and (f) progressively reduce the size of the pharynx, while larynx lowering in step (f) would introduce a markedly complex combination of sphincteric tightening with an increased pharynx volume. There can also be a drawing in of the walls of the pharynx accompanying a strong constrictive manoeuvre. This implicates the palatopharyngeal muscles (and less likely, the pharyngeal constrictors around the throat), but it could just be a reflex of the thyroarytenoid/hyoglossus/hyothyroid buckling manoeuvre.

j. If all these muscle groups adopt their maximally constricted postures, full optimal closure of the airway results.

Lingual retraction, therefore, can be seen to accompany a wide range of laryngeal gestures. It involves far more than just tongue backing. While these complex laryngeal events are occurring, oral actions of the tongue (and actions of the lips) modify sound quality at the same time.

5. Conclusion

In summary, [ɑ] is not just a low back vowel. It is related to the laryngeal constrictor mechanism in a complex chain of events that, ultimately, lead to the complete closure of the airway. The retracted vowels can therefore be considered pharyngeal vowels, once a certain degree of constriction is reached, because the control of the pharynx is also a product of the laryngeal constrictor mechanism. Due to the complexity of the mechanism — as a vertical compressor with back-to-front (aryepiglottic) and front-to-back (lingual) components — the quality of [ɑ] is inherently susceptible to increasing degrees of laryngeal constriction, including constriction of the pharynx, and to varying effects of changing laryngeal/pharyngeal resonances and periodic vibrations. The low lingual component of [ɑ] is secondarily related to the laryngeal constrictor so that any more extreme backing or lowering of a vowel in this region is, by definition of the laryngeal constrictor model, not only a function of lingual movement but primarily a function of changes in laryngeal/pharyngeal cavity shape. This is not to say that tongue shape and oral cavity volume should not continue to be considered the main determiners of auditory and acoustic vowel quality. What it means is that front vowels and open (front) vowels are associated primarily with the action of the front of the tongue and of the jaw; raised vowels are associated primarily with the action of the body of the tongue lifting upward and backward (disregarding for the moment the effect of the lips); and retracted vowels are associated primarily with the action of the complex laryngeal constrictor mechanism, controlling larynx opening, larynx height, and lingual lowering, and affecting concomitant lingual-palatal lowering, and even jaw opening. Retracted vowels are inherently the most susceptible to the effects of this mechanism, but the oral (front and raised) vowels can also be strongly affected by laryngeal constriction. The effects of fronting on raising, of raising on fronting, or of fronting or raising on retraction are not so great as the effect that the multiple qualities associated with retraction can exert secondarily on the oral qualities of fronting or raising.

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