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The laryngeal articulator's influence on voice quality and vowel quality

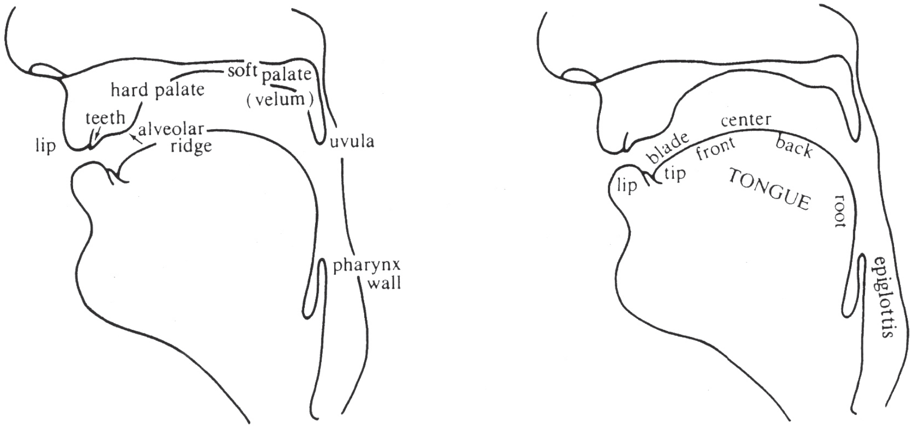
In order to account for sound qualities that emerge from the lower vocal tract, the traditional articulatory model of the vocal tract has to be redrawn. The lower vocal tract incorporates an epilaryngeal tube, aryepiglottic articulators, larynx-height adjustments, and sublingual pharyngeal spaces influenced by epilaryngeal parameters and by lingual-retraction parameters. Laryngoscopic observations reveal how several pharyngeal strictures and laryngeal voice qualities function in a variety of linguistic systems. Parallel cineradiographic, ultrasound, and MRI techniques reveal that laryngeal articulation is critical in shaping tonal register effects and vowel quality. The lower vocal tract is shown to be a significant contributor in shaping the auditory/acoustic output of vowels that are usually defined by uniquely oral parameters. More extreme laryngeal modifications evoke changes to vowel quality that differ by vowel category and by laryngeal effect.

Key words: larynx, epilaryngeal, aryepiglottic, laryngoscopic, vowel quality.

1. *The vocal tract, traditionally*

The objective of this presentation is to redraw the articulatory possibilities of the vocal tract in order to accommodate sound qualities that are produced primarily in the lower vocal tract. The traditional vocal tract model (e.g. Ladefoged, 2001) does not depict a lower vocal tract articulator. Articulations in the lower vocal tract are generally ignored except for the role that the vocal folds play in producing phonation of various types, based largely on the size and shape of the glottis. The traditional model could be called a linguocentric source-filter model. In a source-filter model, glottal aperture is taken to be the deciding factor in the modulation of phonation, and the rest of the vocal tract, or 'supraglottic' vocal tract, is the 'tube' or resonating space where the source is filtered, creating spectral elaborations. In a purely linguocentric model – an articulatory parallel to the acoustic source-filter paradigm, the tongue is assumed to be the primary articulator that produces 'sound shapes' anywhere between the glottis and the lips (with contributions of course from the jaw and from velo-pharyngeal aperture). Figure 1 illustrates the traditional depiction of the laryngeal space, where only the pharynx wall appears as a passive articulator, and only the epiglottis is present as a potential active articulator, presumably associated with the tongue in this regard. There is no depiction of the larynx or glottis at all in this view, but that is presumably because the glottis is assumed to have only one role, dealt with later on in the textbook in a section on 'States of the Glottis,' which also includes descriptions of timing as a laryngeal accompaniment to oral stops (Ladefoged, 2001: 122-132). Phonation types have been elaborately described in articulatory and auditory phonetics, including their acoustic correlates (Catford, 1964, 1977). The modelling of how these various phonation types relate to the structures of the vocal tract and how they are differentiated from each other remains, however, focused on glottal shape in a relatively 2-dimensional conceptualization (Gordon, Ladefoged, 2001). The notion of articulation happening in the larynx is generally discounted. Articulation is commonly thought to be a function of lingual, and mandibular and labial, movements. The larynx is not thought to move in the same ways as the tongue, jaw, or lips, and it has therefore been considered (mistakenly) to be only a housing for the muscles that control glottal aperture.

Figure 1 - *Traditional vocal tract model (Ladefoged, 2001: 3-4). From Ladefoged. Course in Phonetics, 4E. © 2001 South-Western, a part of Cengage, Inc. Reproduced by permission*

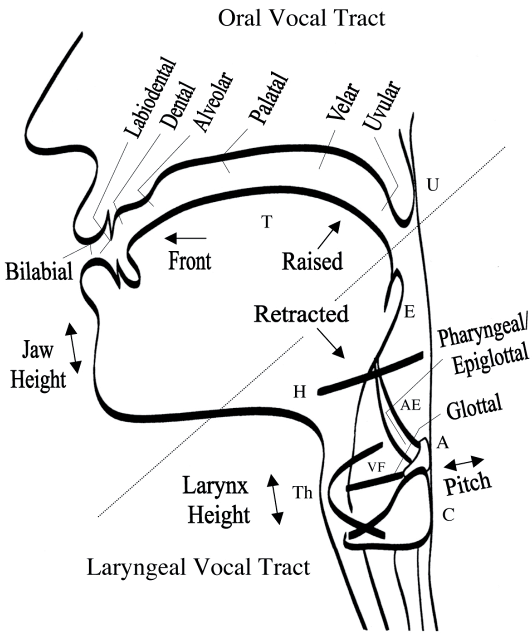


2. *Lower vocal tract articulation, redrawn*

Considerable experimental phonetic research has demonstrated that the lower vocal tract, or laryngeal vocal tract, is more highly elaborated than in lingually-dominated models (Esling, 1996, 2005). The Laryngeal Articulator Model, shown graphically in Figure 2, divides the vocal tract into two parts, a laryngeal vocal tract, beginning at the glottis and continuing upwards to the top of the pharynx below the uvula, and an oral vocal tract, beginning at the uvula and continuing through the lips. This view could be called the 'two-part vocal tract' (Esling, 2010). Actions of the tongue are separated in this model into three primary directions: retracting, raising, and fronting. Retraction of the tongue is allocated to the laryngeal articulator, below the dashed line, because the tongue does not retract, physiologically, without an initiating action occurring in the larynx. This is the principal difference between the Laryngeal Articulator Model and linguocentric models; the tongue is not the primary articulator but rather an accompanying action to a dominantly laryngeal manoeuvre. The actions of the laryngeal articulator reach far beyond just glottal voicing and horizontal-plane alteration in glottal shape or state. The mechanism depicted in Figure 2 is fully elaborated to perform articulations that bear a direct relationship to changes in auditory quality and acoustic resonance. The mechanism also generates various vibratory possibilities. It is therefore a multiple source, giving a more deeply-layered aspect to the notion of phonation types or of glottal state. As we shall see below, there is a substantial vertical aspect to the performance of the laryngeal mechanism, before the airstream reaches the oral section of the vocal tract.

The relationship between the tongue and the laryngeal mechanism (which can also be called the aryepiglottic sphinctering mechanism or the laryngeal constrictor mechanism) has implications for the description of vowel quality. Those vowels in the lower-right corner of the vowel quadrilateral have the potential to be strongly influenced by the action of the laryngeal constrictor, due to the accompanying retraction of the tongue that the constrictor engenders. Vowels in the upper-right corner of the vowel quadrilateral are lingually raised, that is, they are pulled back and upwards, and as such are not as likely to show the effects of laryngealization or pharyngealization (both of which are terms that can be used to describe the general effects of the laryngeal constrictor mechanism, although their phonological usage may refer to more specific phonetic events). Vowels at the left side of the vowel quadrilateral are lingually fronted, and more open vowels exhibit progressively greater degrees of jaw opening, and as such are also not as likely to show the effects of laryngealization or pharyngealization. Thus, vowels such as [ɑ] or [ɔ] can be thought of as having the potential to be more laryngealized or pharyngealized than raised or fronted vowels.

Figure 2 - *The Laryngeal Articulator Model of the vocal tract (Esling, 2005)*



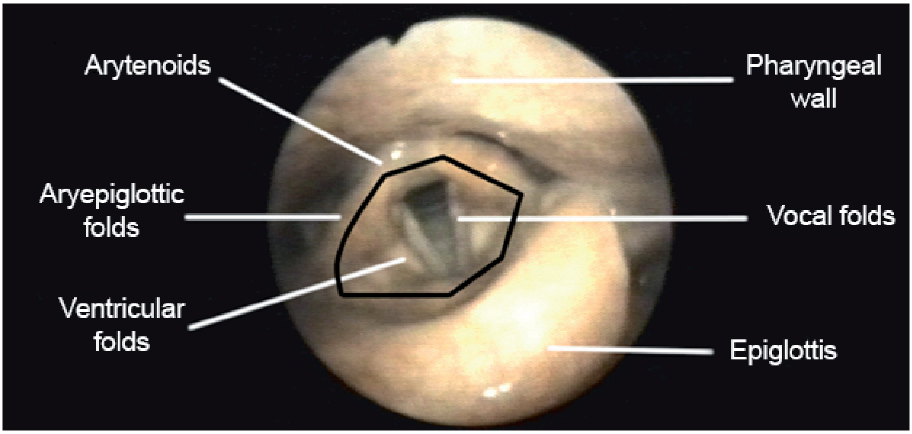
3. *Instrumental approaches to laryngeal articulation*

Our instrumental research over the years has shown that the glottis is not the only source of periodic energy in the larynx and that the ventricular folds and aryepiglottic folds also generate vibrations attested in speech sounds (Moisik, Esling & Crevier-Buchman, 2010). We have also demonstrated that the laryngeal constrictor mechanism controls cavity resonance in pharyngeal articulations, cavity resonance and/or phonation type in 'tonal register' languages, and cavity resonance in 'vowel harmony' languages such as those that have been labelled 'ATR' languages (Edmondson, Esling, 2006). Phonation types have also been realigned with a new perspective on states of the glottis (Esling, Harris, 2005), or more properly 'states of the larynx.' The tools of investigation that we have used in our phonetic research have allowed us to formulate a theory in which the articulatory production of pharyngeal sounds can be explained as being contained within the 'laryngeal articulator' (Esling, 2005). We have examined laryngeal articulation in over two dozen languages from diverse language families across the world to demonstrate the distinctive 'manners of articulation' as well as resonances that the laryngeal articulator can produce.

3.1 Laryngoscopic investigation

Our initial mode of instrumental investigation relied on fibreoptic laryngoscopy, in which endoscopically transmitted images of the lower vocal tract are captured using either a nasally inserted or an orally inserted scope (see Sawashima, Hirose, 1968). Figure 3 demonstrates the view of the articulatory structures in the lower vocal tract, where the distal end of the laryngoscope is just behind and below the uvula. The epiglottis is at the front (bottom), and aryepiglottic folds join the arytenoid cartilages at the back (top, where they hide the oesophageal opening against the posterior pharyngeal wall) to the side borders of the epiglottis, upwards towards the front. The ring designates the aryepiglottic laryngeal 'sphincter,' by which the corniculate tubercles of the arytenoids connect to the cuneiform tubercles of the aryepiglottic folds, the sides of the epiglottis, and the epiglottic tubercle at the base of the epiglottis. This rim forms the closure mechanism that produces the narrowing required for pharyngeal sounds, for what have been called epiglottal sounds, for register adjustments in the larynx accompanying tone, and for resonance modulation in many harmonic systems. The space between the glottis upwards to the aryepiglottic rim is the epilaryngeal tube – a physiologically (and phonetically) critical space in the lower pharynx.

Figure 3 - *A laryngoscopic view of the lower vocal tract, showing anterior structures (bottom), posterior structures (top), and three sets of folds through the length of the epilaryngeal tube*



Full closure of the supraglottic epilaryngeal tube occurs in gagging, coughing, swallowing, and in the phonetic production of epiglottal stop [ʡ]. Far from being a phonetic rarity, epiglottal stop (or epiglottal plosive, sometimes called pharyngeal stop by fieldworkers) is widely attested. At least, it has been widely observed since our description of it established what it is and how it is produced (Esling, 2003; Esling, Fraser & Harris, 2005). Catford did introduce the term 'epiglotto-pharyngeal' to distinguish more extremely retracted sounds from those labelled pharyngeals (Catford, 1968: 326), but although he identified sounds that he would have labelled epiglottopharyngeal fricative, approximant and trill, he was equivocal about the nature of an epiglottopharyngeal stop articulation. Instead of the tongue articulating against the posterior wall of the pharynx, which was the widely-held view at that time, we observe the aryepiglottic folds to advance forwards and upwards from their posterior, open position towards the base of the epiglottis, in a gesture that finishes by completely arresting the passage of air from the lungs. Full aryepiglotto-epiglottal closure results in a pharyngeal/epiglottal stop. Epiglottal stop /ʡ/ is a phoneme in Tigrinya (Semitic), in the Interior Salish languages of British Columbia, and in Nuuchahnulth (Wakashan). It occurs in Iraqi Arabic as a realization of the geminate pharyngeal /ʕʕ/, and it is attested in Berber. It is also known to occur in a number of Caucasian languages.

Tigrinya, Nuuchahnulth, and Iraqi Arabic also have a voiceless pharyngeal fricative /ħ/ in their phonologies, and this sound is homorganic with epiglottal stop. Some Caucasian languages may differentiate a pharyngeal from an epiglottal fricative, but this likely due to a difference in larynx height, where the pharyngeal has a lower larynx position, and the epiglottal has a higher larynx position and therefore smaller resonating spaces and higher-pitched spectral attributes. In languages that have an epiglottal stop phoneme, however, the stop will generally have the same place of articulation (the aryepiglottic folds against the tubercle of the epiglottis) and the same relative larynx height as the fricative. The same applies to languages that also have a voiced pharyngeal approximant /ʕ/ and/or a pharyngeal/epiglottal trill. In this context, it should be noted that the pharyngeal/epiglottal place of articulation is one identical column in the elaborated IPA chart contained in Esling (2010) and in Coey, Esling & Moisik (2014).

The voiced pharyngeal approximant /ʕ/ appears in many languages, with the same articulatory attributes as the stop and fricative, distinguished only by the degree of approximation of the aryepiglottic folds and by glottal vocal fold voicing. As mentioned for Iraqi Arabic, stopping the airflow of [ʕ] by the slightest closure of the aryepiglottic mechanism results in an epiglottal stop [ʡ]. Although the pharyngeal fricative and approximant appear together in the IPA chart, they have demonstrably different manners of articulation, as argued by Laufer (1996). A number of degrees of approximation and of frication are represented for the Pharyngeal/Epiglottal column in the elaborated IPA chart contained in Esling (2010). This same chart is reproduced on the main page of the app, *iPA Phonetics* (Coey, Esling & Moisik, 2014). Iraqi Arabic is a variety in which the pharyngeal approximant /ʕ/ or the pharyngeal fricative /ħ/ can become trilled. This involves the aryepiglottic folds at the upper margin of the epilaryngeal tube, which vibrate, each one against the area around the epiglottic tubercle. When the space of the laryngeal constrictor between the advancing aryepiglottic folds and the epiglottal surface becomes very narrow, as for /ʕ/ or /ħ/, the potential for the aryepiglottic folds to vibrate increases. In Iraqi Arabic, this occurs when /ʕ/ is spoken in a more forceful prosodic context or when /ħ/ is lengthened as a geminate intervocalically. We have seen that when /ʕ/ is lengthened as an intervocalic geminate, it is generally realized as a full stop [ʡ]. Geminate /ħ/ nearly always trills. It could be considered more likely that the voiceless fricative would engender trilling, because of the propensity of the voiceless airstream to induce vibration of adjacent structures. We have used the symbols for an epiglottal fricative to represent these sounds, [ʢ] and [ʜ], since the epiglottal label has been used to imply stronger articulation, and because trilling is a more constricted manner of articulation than either [ʕ] or [ħ]. The other way in which [ʕ] or [ħ] could be enhanced and logically represented by the symbols [ʢ] and [ʜ] would be through a more extreme raising of the larynx. Thus, aryepiglottic trilling and extreme compaction of the epilaryngeal space are complementary gestures that warrant the use of the 'epiglottal' symbols [ʢ] and [ʜ]. This usage is arguably consistent with Catford's (1968) intentions.

In Moisik, Esling & Crevier-Buchman (2010) the vibrations of the aryepiglottic folds are analyzed in detail. The two folds are shown to vibrate in two different phases, which is not unusual for independent structures that do not vibrate against each other but which vibrate against separate parts of the base of the epiglottis. In our research, the left fold vibrates at the same frequency as the vocal folds, but the right fold vibrates at half that frequency, ostensibly due to different angles and pressures with which the cuneiform tubercles of the folds are pressed up against the epiglottis. It may be that many people share this pattern, or at least exhibit a pattern where the two folds are in different phases. Like epiglottal stop, aryepiglottic fold trilling is not unusual physiologically. It occurs during throat clearing and often during loud yelling.

3.2 Cineradiographic evidence

Another method of observing the articulatory functions of the lower vocal tract is by means of cineradiography. Cineradiographic videos of epiglottal stop, voiceless aryepiglottic trill, and voiced aryepiglottic trill were performed at the at Instituto de Ciências Biomédicas, Departamento de Anatomia, Universidade Federal do Rio de Janeiro, with the collaboration of Milton Melciades Barbosa Costa and Leonardo Fuks. Each short video was then analyzed using automated measurements developed in Matlab by Scott Moisik. The epilaryngeal tube and the pharyngeal tube above it were each defined as a region of interest (ROI) in Matlab – a two-dimensional area. In the black-and-white sagittal images of each video clip, approximate areas of the epilaryngeal tube area and the pharyngeal tube can be calculated as the different luminosity thresholds of pixels in each ROI change over time. Each area is measured and tracked over time for each ROI, with most-luminescent pixels indicating a larger area (more open in terms of volume), and least-luminescent pixels indicating a smaller area (more closed in terms of volume). An aryepiglottic-fold-to-vocal-fold distance is also measured, and an epiglottis-vocal-fold angle is calculated by drawing one line from an anterior point on the neck along the vocal folds and another line up along the border of the epiglottis. Measurements were also taken of the height of the cricoid cartilage relative to an arbitrary reference point beneath.

Results for [ɑʡɑ] show that the epilaryngeal tube area decreases to zero during the stop, while the pharyngeal tube area above remains about 75% open. Aryepiglottic-fold-vocal-fold separation also reduces to zero, and the angle between the vocal folds and the epiglottal border above reduces to zero degrees. This is powerful evidence that epiglottal stop is an articulation of full closure and indicates precisely where and how that closure occurs. Results for [ɑʜɑ] show a similar but less extreme pattern. Epilaryngeal tube area decreases to around 40% during stricture, while pharyngeal area above remains about 75% open. This implies that epilaryngeal tube volume is the deciding factor in the articulation of pharyngeals, while (upper) pharyngeal volume is less significant. Aryepiglottic-fold-vocal-fold separation is around 30% of maximum, and the angle between the vocal folds and the epiglottal border above reduces to about 20 degrees. Results for [ɑʢɑ] show tighter constriction than for voiceless [ʜ]. Epilaryngeal tube area decreases to around 10% during stricture, while pharyngeal area above remains about 60% open. Here again, epilaryngeal tube volume is the deciding factor in the articulation of the pharyngeal. Aryepiglottic-fold-vocal-fold separation decreases to around 10% of maximum, and the angle between the vocal folds and the epiglottal border is around 15 degrees. In all three of the videos, the point of maximum stricture is clearly the arytenoid and aryepiglottic structures approximating or closing against the tubercle at the base of the epiglottis. This action pulls the tongue and epiglottis backwards, towards but not touching the posterior pharyngeal wall. Since the pharyngeal space (between the retracted tip of the epiglottis and the arytenoid-aryepiglottic top of the epilaryngeal tube) only reduces partially in area (and presumably volume), we can conclude that these pharyngeal/epiglottal articulations are not primarily a lingual-retraction articulation but rather a primary aryepiglottic articulation (inducing changes to epilaryngeal tube area, viz. volume). These changes are laid out in detail in Moisik (2013).

3.3 Ultrasound of the larynx

Another technique of examining laryngeal function that provides a view of the laryngeal articulator from above as well as from the side in the vertical plane is to combine laryngoscopy with laryngeal ultrasound. The technique, developed by Scott Moisik and known as 'simultaneous laryngoscopy and laryngeal ultrasound' (SLLUS), is illustrated in a study of tonal pitch and register in Mandarin by Moisik, Lin & Esling (2014). Photographs in that article illustrate how the two instruments are used together in the lab. The two methods complement each other; laryngoscopy working well to evaluate larynx state, and ultrasound working well to evaluate larynx height. The mapping of how laryngeal structures correspond to the view obtained from the ultrasound probe placed against the side of the thyroid cartilage is also illustrated in the *iPA Phonetics* app (Coey, Esling & Moisik, 2014). This placement of the probe allows three levels of valves (vocal, ventricular, aryepiglottic) and the epiglottis to be visualized in a side-on representation. Viewing the larynx with ultrasound in the vertical dimension is a particularly effective way of interpreting the variable stricture of the valves of the larynx (Edmondson, Esling, 2006).

Simultaneous laryngoscopy and laryngeal ultrasound of epiglottal stop [iʡi] is evaluated using optical flow analysis of movements in the ultrasound, synchronized with the video of the laryngoscopic image. As the laryngeal articulatory structures rise, flow vectors can be summed and converted to millimetres to track global vertical displacement during laryngeal closure. Elevation of the larynx can be seen in the laryngoscopic video, as the structures rise and compact, approaching the distal end of the scope and reflecting more light. The synchronized ultrasound track allows these movements to be quantified. The onset of closure is accompanied by early approximation of the vocal folds and the ventricular folds, followed by systematic elevation of these coupled sets of folds and of the aryepiglottic folds. As this occurs, the tongue begins to retract. It is interesting to note that closure of the aryepiglottic sphincter appears to be completed prior to full elevation of the larynx. Once maximum elevation is achieved, the vectors tracking the top of the epilaryngeal tube indicate that the aryepiglottic folds are releasing and beginning to drop and that the tongue is beginning to advance, while the glottal-level structures are still maintaining raising. Immediately after this, the glottal level starts to drop, the aryepiglottic folds begin to descend, and the tongue moves forward, leaving the pharyngeal cavity open. In the production of [iʜi], there is an immediate transition from vocalic voicing to laryngeally constricted 'funnelling' of the epilaryngeal tube (into the state of 'whisper') to generate whispered friction as the aryepiglottic folds also begin to vibrate for the voiceless pharyngeal trill. The constrictor (sphincter) continues to narrow as the larynx rises. Voicing for the second vowel begins as the larynx reaches its most elevated point, with the larynx steadily lowering as voicing continues. For [iʕi], because it is fully voiced, it is more difficult to see in the laryngoscopic video where transitions occur. Ultrasound, aligned with the speech waveform, helps us to determine that the larynx continues to rise from the first vowel into the voiced pharyngeal trill. The onset of the second vowel coincides with maximum larynx height, after which the larynx descends to baseline as the mechanism opens at the end of voicing. An interesting comment to add is that many F0-extraction algorithms fail to detect the periodicity of voicing beginning exactly at the point where aryepiglottic trilling starts, since aryepiglottic vibrations can conflict with vocal fold vibrations. However, Scott Moisik's custom F0-extraction algorithm is able to deal with these multiple sources and does a good job of tracing F0 throughout the production of an acoustically challenging sequence such as [iʕi].

These results tell us that pharyngeals/epiglottals are primarily a function of epilaryngeal tube constriction (based on area, but extrapolating to volume). Laryngeal ultrasound is shown to be a suitable technique to evaluate larynx height. It demonstrates that larynx height is a factor in producing pharyngeals/epiglottals and that larynx height is closely coordinated with the action of closing and opening the aryepiglottic sphincter. The combined SLLUS methodology provides us with a means to measure parameters necessary to explain the function of larynx height. We surmise that if larynx height does not correlate with pitch, then the target must be a pharyngeal, as we have seen in these instances. If, on the other hand, larynx height does correlate with pitch, then we must be dealing with a target that is a tonal feature. This allows us to presume that a language such as Iraqi Arabic produces pharyngeal/epiglottal consonants by using the laryngeal constrictor mechanism in coordination with larynx height, whereas a Tibeto-Burman language, where constrictor function and pitch both characterize the 'register' of the syllable, will dedicate larynx height primarily to the production of tone. That is not to say that every dialect of Arabic should favour a raised larynx per se – only that the production of the pharyngeal stricture and larynx height are coordinated. And it is not to say that every Tibeto-Burman language will ignore the relationship between laryngeal constriction and larynx height – only that the tendency is for larynx height to be associated with pitch changes more than with laryngeal constrictor states.

4. *Laryngeal articulation and vowel quality*

Just as laryngeal articulation is related to phonatory quality and to tonal quality (of necessity, because both phonation and pitch changes are sited within the larynx), the fact that the laryngeal space is an articulator proper and not just a vibration generator means that vowel quality cannot be described auditorily or calculated acoustically based only on the parameters of the oral vocal tract. The shapes, volumes, and movements of the laryngeal vocal tract must also be taken into account. As it stands, the study of vowel quality tells us very little about the contribution of lower-vocal-tract resonances to the auditory or acoustic characteristics of vowels.

One way of looking at the configurations of both the oral and laryngeal vocal tracts together is through magnetic resonance imaging (MRI). The view is sagittal, giving an initial impression of area, much like cineradiographic images, but parallel slices can be obtained at successive depths to create data on volume. We have collected preliminary MRI data to test the procedure and to investigate whether it is possible to identify changes in oral articulator posture (and by extension differences in vowel quality) due to contrasting postures of the laryngeal articulator. Data capture is based on earlier pilot work to identify the articulatory nature of glottal stop and of creaky voice using MRI (Moisik, Esling, Crevier-Buchman, Amelot & Halimi, 2015). The MRI tests comprise imaging a series of peripheral vowels and then comparing those same vowel targets when produced with contrasting settings of the laryngeal mechanism, initially in midsagittal section. The MRI images are all static (sustained postures were maintained). The laryngeal conditions include glottal stop (the vowel followed by [ʔ]), epiglottal stop (the vowel followed by [ʡ]), creaky voice (the vowel produced with creaky phonation [̰]), and raised larynx voice (the vowel produced with [ˤ] quality). Canonically, raised larynx voice can be interpreted as the same as pharyngealized voice but higher in the pitch range. In theory, the vowel productions will show predictable positioning of the tongue in the oral cavity, and the laryngeal conditions will evoke not only changes in the 'source' (as in a lingually-based model) but also (because the larynx is also an articulator) changes in the articulatory shape of the lower vocal tract. Presumably then, there should be an interaction between the oral production of the vowel and the laryngeal production of the lower-vocal-tract coarticulation, whereby vowel quality is regulated and normalized, as it were, for the context.

To outline some preliminary observations, the glottal stop context (the vowel followed by [ʔ]) has interesting ramifications for tongue positioning. Generally, the tongue appears to tilt backwards and downwards, as on a fulcrum with the jaw tilting up slightly, when glottal stop closes the vowel. This changes, systematically, the lingual articulation for the vowel. The larynx as a whole does not appear elevated as a function of the glottal stop; in fact, the major effect on the larynx seems to be lowering. This helps us to understand the gradational nature of the action of the laryngeal constrictor mechanism; that is, glottal stop cannot necessarily be predicted to have the same laryngeal behaviour, or at least laryngeal height behaviour, as epiglottal stop, for instance. The epiglottal stop context (the vowel followed by [ʡ]) uniformly involves elevation of the larynx as a whole and simultaneous retraction of the tongue to close off the epilaryngeal tube and significantly narrow the lower pharynx behind the epiglottis. This does not mean, however, that the whole of the tongue is pulled backwards or downwards, as it appears to be in the glottal stop context. Instead, the tongue may have to stretch to attain the upwards approximation necessary to produce sufficiently fronted [i] or sufficiently raised [u]. In these cases, the laryngeal coarticulation forces the tongue to be pulled in two directions at the same time to achieve an adequate vowel quality target. For vowels in the context of creaky voice (the vowel produced with creaky phonation [̰]), the base of the tongue and the jaw appear to swivel downwards (towards the glottis) as the antero-posterior dimension of the larynx shortens. In the raised larynx voice (produced with [ˤ] quality) context, the tongue is pulled backwards and downwards, as it is for glottal stop, but the antero-posterior dimension of the larynx is stretched (lengthened) rather than shortened. This is ostensibly because a raised larynx voice or pharyngealized voice quality requires open air spaces under the tongue/epiglottis to create resonances. The descending tongue body/root is angled back to lie almost parallel above the glottis, which resembles the posture for epiglottal stop, but the need to keep the epilaryngeal tube cavity and the subepiglottal pharyngeal space open means that the cervical spine has to retract posteriorly while the larynx at the front has to advance anteriorly and tilt upwards slightly. By contrast, in the creaky voice context or in the epiglottal stop context, these spaces are effectively obliterated. Similarly to epiglottal stop, the severely retracted tongue of the raised larynx voice context means that the upper part of the tongue must stretch upwards to achieve front vowels ([i ɪ e ɛ æ]) or the raised vowel [u]. Thus, pronounced tongue retraction is common to both epiglottal stop and raised larynx voice due to the severe degree of laryngeal constriction; however, the epilaryngeal space below the flattened epiglottis is spread out anteriorly and posteriorly in raised larynx voice in order to preserve resonance cavity viability. Neither glottal stop nor creaky voice engender the same degree of constriction or retraction.

These preliminary observations suggest that the laryngeal articulator plays a considerable role in the shaping of resonance cavities that contribute to vowel quality. Each laryngeal condition examined here exerts a different effect on the configuration of the lower vocal tract and on the tongue and jaw, especially the lower part of the tongue. Nevertheless, the oral vocal tract preserves the role of distinguishing close vowel quality, even when laryngeal effects are simultaneously applied. The production of fronted [i] or of raised [u] requires the body of the tongue to front or raise even if the mass of the lower tongue is being pulled into the laryngeal space. The jaw closes to assist in these articulations, but the tongue must articulate the elevation movements at the same time as the retraction movements. When this happens, the tongue is pulled in two directions, upwards and downwards. Open vowels behave differently with respect to the relationship between the oral and the laryngeal articulators. The suggestion can also be made that tilt, on a line coursing anteriorly and upwards from the cricoid ring to the front of the jaw, is a function of the type of laryngeal configuration and not just of pitch.

The conclusion can be drawn that models of vowel quality description that consider only oral configurations as the components of articulation that generate the resonances that are heard as auditory quality or seen as spectral magnitudes must be considered deficient. By the same token, to consider that pitch (vocal fold vibratory frequency) is the only laryngeal component that interacts with vowel quality is also insufficient to account for the interactions that occur between the larynx and the oral vocal tract. To complete all aspects of vowel quality description, a triangulation must occur. The geometric relationships among three sets of physiological activities must be reconciled. The first is clearly the positioning of the articulatory structures (primarily the tongue) in the oral vocal tract – an orientation that differs substantially depending on whether the target vowel is close or open. The second is the positioning of the laryngeal articulatory structures in the lower vocal tract – configurations that differ depending on whether the sound being produced is a continuant or a stop, slightly closed or fully closed, or voiced or voiceless. The third is the role of pitch – not only adding vibratory frequency to the speech signal but also requiring that the laryngeal structures change position as glottal length shortens or stretches. The first parameter (oral) is interdependent on the second (laryngeal). Even if the laryngeal cavity is wide open, we must assume that the size and volumes of the laryngeal vocal tract are contributing to the auditory/acoustic characteristics of the ostensibly lingually-shaped vowel. The second parameter (laryngeal) becomes increasingly important as the laryngeal articulator departs from its open position and adopts a more constricted setting. Various constricted settings contribute different aspects of tilt (inclination of laryngeal structures to tongue to jaw), depending on the openness of the epilaryngeal spaces (usually a requirement for the resonance of these spaces), on the kind of phonation type that is being produced (where low-pitched types require a different laryngeal configuration from high-pitched types), and on whether multiple vibrators through to the top of the epilaryngeal tube add more complex requirements to the positioning of structures higher up the chain (because the bottom of the epilaryngeal tube relates differently to superior structures than does the aryepiglottic top of the epilaryngeal tube). The third parameter (pitch) is known to have an intrinsic relationship to vowel quality (Whalen, Gick, Kumada & Honda, 1998), as laryngeal tilt influences the shape of superior structures in their oral performance of the target vowel. However, since laryngeal tilt can also occur as a result of the performance of particular laryngeally constricted targets, it behooves us in our research on vowel quality to consider both the influence of tilt resulting from a manoeuvre adopted to generate a particular pitch as well as the influence of tilt resulting from a manoeuvre adopted to realize a combination of laryngeal postures. Since tilt can occur along different axes, laryngeal tilt arising from a pitch setting alone cannot account for the full chain of articulatory events that bind the lowest (glottal) level of the vocal tract to oral vowel articulation. In this chain of events, laryngeal articulatory configuration is the key intermediary factor – one that plays a more common and influential role than often suspected. The intricacies of these sequential and interconnected relationships throughout the vocal tract are the subject of a paper by Moisik, Esling, Crevier-Buchman & Halimi (submitted).

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