ACOUSTIC ANALYSIS OF PHARYNGEAL APPROXIMANTS, FRICATIVES, TRILLS AND STOPS

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Introduction

The pharyngeal consonants have been problematic phonetically and phonologically. This paper is an attempt to use acoustical data and language data to support the notion of four manners of articulation in the region of the pharynx. Since this area of the vocal tract is difficult to see it is difficult to understand how structures in the larynx and pharynx move with respect to each other. This causes problems with phonological theories in determining the features that are associated with pharyngeal segments and that are involved in phonological processes. The goal of this research is to clarify the confusing and imprecise terminology used to describe behaviour in the pharynx.

This investigation illustrates the importance of considering phonological phenomena when developing a good phonetic taxonomy. It is important to note the phonetic and acoustic qualities of a sound but ultimately, the sound needs to be relevant to language in order to be included in a phonetic taxonomy, such as the International Phonetic Association (IPA). This investigation shows acoustically and physiologically that the pharyngeal area of the vocal tract can produce plosive, trill, fricative and approximant manners. The references to language data suggest languages that use pharyngeal articulations may treat them as varying manners. Data from one language suggests there is more than one place of articulation in the region of the pharynx. Re-considering these language examples as varying manners of articulations may be provide a plausible alternative.

Traditionally, consonants are described with respect to 'place' and 'manner' of articulation. For instance, sounds produced by the lips are classed as *labial*. At this place it is possible to produce four manners of articulation:

1. A stop [b] that involves complete closure of the lips.
2. A trill [ʙ] that involves rapid stops in succession.
3. A fricative [β] that requires the lips to be close enough to cause passing air to be turbulent.
4. An approximant [w] that involves the lips approximating, or coming together but not close enough to cause turbulence in the airstream.

Based on auditory assessments of pharyngeal and epiglottal productions it is hypothesized, that the same manners mentioned above for the labial place can be produced at the pharyngeal place. This assertion is based mainly on the auditory descriptions of pharyngeal sounds such as those described in Krauss (1979) and Esling (personal communication) as well as personal observations. It appears, that varying manners are described phonologically (Bessell 1992, 1993, Rose 1976, Krauss 1979). Varying manners in the pharynx implies the use of characteristics that define manners in all places of articulation. That is, stops imply complete closure, trills rapid stops, fricatives a noise component, and approximants involve the least amount of constriction.

The places of articulation, according to the International Phonetic Alphabet (IPA), are shown in Figure 1. The thyroid and cricoid cartilages have been drawn in to illustrate the orientation of the larynx, note that the oral cavity contains nearly all places of articulation. This is largely becuase the tongue is more agile in the oral region and the tongue is the primary articulator for most speech sounds. Esling (1996) argues that the aryepiglottic folds are the main articulator in the pharynx. This interpretation differs slightly from Laufer's (1979) description that the epiglottis is the main articulator in the pharynx. The issue of specifying the articulator in the pharynx will not be challenged here, the goal here it is a clarify 'place' and manner of articulation. The articulator does not require consideration here since the manner of articulation in any region is defined by stoppages or friction as mentioned above and not fine tuned adjustments that might distinguish variations on a manner of articulation, such as comparing an apical-alveolar fricative with a laminal alveolar fricative.

Figure 1 shows the pharynx as one region. The IPA chart, however, also postulates an epiglottal place (under 'other symbols' on the chart), in order to distinguish between consonants produced in the pharynx (see IPA chart in appendix). The acoustical and phonological data presented here will show that the consonants classified as epiglottal are not distinct in place of articulation from what have been called pharyngeal articulations.

The advantage of looking at pharyngeal segments phonologically is that their classification is determined by their use in the language. In most cases a certain class of sounds will behave similarly throughout a particular language. In the case of pharyngeal consonants, they are produced in the throat where it is not possible to see the articulation. This may cause difficulty for listeners since it is important to have visual cues in speech. This is known as the McGurk effect and is illustrated by the difficulty in watching dubbed foreign films; dubbed words do not match the speaker's movements, which confuses the viewer. However, in the case of pharyngeal consonants, the phonology, i.e. how the sound is used in the language, helps to eliminate confusion. Phonological consistencies are noted cross-linguistically which contributes to producing a taxonomy like the IPA chart.

This paper considers the general acoustic, auditory and physiological plausibility of manners of pharyngeal articulations. As well, languages that use sounds produced in the pharynx are examined in an attempt to support the pharyngeal region as a place of articulation that is capable of producing varying manners of articulation. The phonetic facts will be considered along with reference to aspects of their phonological role in the language.

The paper is organized as follows: First, a short section covering background information will be presented, followed by sections dealing with each proposed manner of articulation in the pharynx. Each section will consider one manner of articulation starting with the proposed pharyngeal *plosive*, *trill*, *fricative* and *approximant*. In each section, the videolaryngoscopic data collected from a one phonetician will be described acoustically. The last part of each section will discuss languages that make use of the proposed manners of articulation phonologically. Following the manners of articulation, section 5 will discuss an interpretation of the Agul consonant inventory. Agul is a Nako-Dagestanian language spoken in the northeast Caucasus that contains both pharyngeal consonants as represented on the IPA chart and the epiglottal consonants. The different manners of articulation discussed in this paper will provide an alternate interpretation of the Agul consonant inventory.

Background

In order to observe movements in the pharynx, a flexible fibreoptic nasendoscope is inserted through the nose and is positioned just behind the velum (see Figure 1). This gives the view seen in Figure 2. The pertinent structures are labeled and discussed with respect to the manners in which they participate. In general, Figure 2 represents the vocal tract at rest, as in quiet breathing. The *epiglottis* is attached to the base of the tongue, and the *pharyngeal wall* extends down the back of the throat. It may be useful to examine this figure along with Figure 1 in order to better understand the position of structures within the larynx and pharynx.

The acoustic output that correlates with the video is analyzed using the Computerized Speech Laboratory (CSL) 4300A and Analysis by Synthesis Laboratory (ASL) from Kay Elemetrics Corp. Two software packages were necessary in order to describe the varying manners of articulation. For examples, the most notable characteristics of a pharyngeal plosive appear to be in the acoustic waveform. This was confirmed by creating, or synthesizing a pharyngeal plosive from a glottal plosive. The spectrogram alone of a plosive does not show any obvious difference between glottal stop and the pharyngeal stop. The qualities of a trill can be seen in the acoustic waveform because of spacing of low amplitude sections. The fricative and approximant formant relationships are seen using a spectrographic analysis of a VCV sequence. These techniques are covered in more detail within the sections. The language data are taken from the Phonetic Database (PDB) from the University of Victoria and from Sounds of the Worlds Languages (SOWL) from UCLA.

1. The Pharyngeal Plosive [ʡ]

Viewing a pharyngeal plosive through a nasendoscope shows the larynx, the structure that contains the vocal folds, raising up to meet the epiglottis (see Esling Figure 3, this issue). This is different from a glottal stop where the larynx is closer to its rest position (as in Figure 2) and only the vocal folds close.

Stops in the oral region are distinguished acoustically according to their formant transition to the following segment. These transitions are visible in the spectrogram and used in synthesizing oral stops. However, the spectrogram for both the pharyngeal and glottal stop, in the environment of [ɑ], show no formant transitions. Theoretically, the first formant frequency should increase from the stop to the vowel since vocal tract constriction generally is associated with a low first formant and, since a stop involves complete constriction (Kent 1992 p.116). F2 and F3 are considered cues for place of articulation which would predict no formant transition since the vowel [ɑ] is used and involves constriction in the pharynx. The fact that no transitions are visible provides evidence for the fact that [ɑ] is articulated in the pharynx. Butcher and Ahmad (1987) illustrate spectrographic evidence of formant transitions with an [i] vowel that show F1 lowering from the stop to the following vowel and F2 and F3 raising. This is consistent with formant behaviour from [i] to [ɑ], the pertinent information for the pharyngeal stop in the environment of [ɑ] appears in the waveform.

The top waveform of Figure 3 is the glottal stop; the first part of the waveform corresponds to the vowel [ɑ] and the straight horizontal line portion is the stop. The bottom waveform is the pharyngeal plosive with the same [ɑ] vowel. In the acoustic waveform the vowel preceding the stop is shorter and the closure, or stop portion, is longer than the glottal stop. This is similar to a lenis/fortis type distinction as described in Ladefoged and Maddieson (1996) where, in this case, the pharyngeal stop requires more articulatory force. The implications of a pharyngeal component in the lenis/fortis description of stops in languages, such as Korean, is not expanded here but is certainly worth investigating, since the results could better define the fortis stops as pharyngeal rather than the less precise terminology of lenis/fortis.

The pitch of the vowels preceding and following the pharyngeal consonant is also higher. Increasing pitch is sometimes achieved by raising the larynx (Esling, Heap, Snell and Dickson, 1994). Therefore, it is reasonable to assume that raising of the larynx observed in the video data would correlate with an increase in pitch. The characteristics of vowel shortening, stop closure lengthening and increased pitch in the pharyngeal plosive are confirmed by taking the glottal stop and changing these parameters using synthesis software to create a pharyngeal stop. The adjustments result in a sound, judged by the phonetician and a Farsi[1] speaker, to be similar to the original production of a pharyngeal stop.

This plosive-type behaviour is described in Arabic by al-Ani (1970) as the more common allophone of the voiced pharyngeal fricative in Arabic. Butcher and Ahmad (1987) state alternatives in Iraqi Arabic to the pharyngeal fricative as either a pharyngeal approximant or stop articulation. In Agul, the Caucasian language mentioned earlier, an epiglottal plosive is noted by Ladefoged and Maddieson (1996). Examining the pitch and amplitude of this Agul example reveals an increase in pitch of the vowel preceding the stop but not following. Unfortunately, there are no examples of glottal stops provided in the SOWL database, and attempts to change the pharyngeal stop into a more

[1]Farsi is an Indo-European language that contains pharyngeal consonants.

glottal sounding stop were not successful. This failure to synthesize is likely due to the poor quality of the original recording which is difficult for the synthesis algorithm to accommodate.

With respect to the phonological evidence for the use of pharyngeal plosives in language, Rose (1976) describes a plosive in the Ahousaht dialect of Nuuchahnulth (Nootka), a Native North American language. The /ʕ/ appears to alternate with \q\, the uvular stop, providing evidence for \ʕ\ as a plosive. Also, Jacobsen (1969) argues proto-Nootkan uvular stops merged to \ʕ\. Massett Haida also contains a pharyngeal that seems to pattern similarly to Ahousaht and exhibit, acoustically, pharyngeal stop-like articulation, i.e. complete closure, or stoppage in the waveform (Bessel 1992).

The languages discussed above appear to make use of a stop that is more massive than a glottal stop but that can sometimes be confused auditorily with fricative-like behaviour. Since articulation in this area of the vocal tract is not as precise as in the front oral region it is likely there may be some confusion in production. Moreover, there are no visual cues to aid the listener as with more fronted articulations making perception and production difficult. It is important then, to consider how the language uses the segment in the phonology in order to determine the status of manner of articulation.

2. Pharyngeal trills [ʜ, ʢ]

Trilling in the pharynx has not been considered within the formal framework of the IPA. However, using the laryngoscope it is possible to view, in certain situations, the aryepiglottic folds approximating medially and anteriorly and trilling. Esling's Figures 6 and 7 (this issue) show this as well as any still photo can. The film speed (30 frames per second) is slower than the rate of trilling therefore, the pictures do not show all phases of movement. The arrow points to the aryepiglottic fold that is slackened and trilling due to the larynx raising toward the epiglottis.

These pharyngeal segments could be thought of as 'strong' fricatives since the trilling is often not as clearly audible as lingual trills. Visual evidence in the phonetician's production of the epiglottal fricative however, support trilling as a distinguishing factor rather than degree of friction.

Trills described in other places of the vocal tract, (i.e. the alveolar or uvular regions), are described acoustically by low amplitude segments in the waveform occurring about 25 times per second. The waveform in Figure 4 illustrates these quick stops. These low amplitude segments occur about 50 times a second which is faster than the lingual trills. It is plausible that the aryepiglottic folds would vibrate faster than the tongue since they are considerably less massive and dense. However, this vibration may not rely solely on the mass of the aryepiglottic folds. It may be more complex and involve activity of the vocal folds, at least in the voiced trill. This trilling is also visible in the phonetician's voiceless trill, except that trilling is about 40 Hz. While consideration of vocal fold involvement in aryepiglottic trilling is beyond the scope of this investigation, the fact remains that trilling activity is produced in the region of the pharynx by the aryepiglottic folds.

Trilling-like qualities in the pharynx have been described in Hydaburg Haida (Krauss 1979, in Bessell 1992), !Xóõ (Traill 1986) and in this investigation with respect to Agul[2]. The Hydaburg Haida description is an auditory description and not supported by an acoustic description to date. Bessell (1992) has suggested that this segment behaves more like an affricate phonologically.

In !Xóõ, Traill (1986) provides a video and acoustic description similar to this investigation, however, the trilling Traill describes is a quality applied to vowels rather than the [ʜ] consonant referred to here and in Agul. He measured trilling like qualities that occur about 50 times per second, similar to the author's observation. Traill's account also describes the aperiodic, or irregular nature of

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[2]Hydaburg Haida is a language isolate belonging to the Na-Dene phylum, !Xóõ) is a Khoisan language of the San subgroup and Agul is a Nako-Dagestanian language of the north east Caucasus.

trilling that is observed here. The trill produced by the phonetician in Figure 4 does not show much irregularity, likely because the trill is produced in a controlled manner, and is produced in isolation. A speaker of !Xóõ may show more regular trilling if asked to produce the trilled vowel in isolation.

The use of trilling in !Xóõ is not as a consonant segment but more like a phonation type superimposed onto a vowel. This phonation type is used distinctively in the language. This poses a problem for phonological theory since the feature [voice] is no longer adequate with such phenomena. For this investigation, the evidence of trilling capabilities in the pharynx is pertinent, leaving the phonological problem open for discussion.

According to the SOWL database, Agul has a distinction between pharyngeal and epiglottal segments. This implies there are two regions in the pharynx that can act as places of articulation. The assumption here is that the pharynx acts as one place of articulation with varying manners. Auditorily, the Agul epiglottal fricative and the phonetician's example of a voiceless pharyngeal trill are very similar. The Agul language example from SOWL contains background noise in the recording which makes instrumental analysis difficult, nevertheless, the example could be argued to have trilling like qualities in the spectrogram as seen in Figure 5. The existance of broadly spaced striations is visible during the consonant production.

From this data, it appears at least two languages make use of trilling behaviour in the pharynx. One language uses the segment as a consonant the other uses the behaviour as a voice quality applied to a vowel. This is both interesting and problematic for theoretical linguistics, but phonetically, it provides evidence for the manner of trilling in the pharynx.

3. The Voiceless Pharyngeal Fricative [ħ]

The voiceless pharyngeal fricative is the least controversial of the pharyngeal articulations since it has been observed acoustically in Semitic languages by investigators such as in Butcher and Ahmad (1987).

Laryngoscopically, the pharyngeal fricative involves the epiglottis approximating the pharyngeal wall and the larynx raising as in Esling's Figure 5 (this issue). The spectrographic data illustrate the fricative well. Fricatives are characterized by noise or aperiodic behaviour in the spectrogram, as shown in Figure 7(a) for the pharyngeal fricative. The vowel portions of the spectrogram show clear vertical striations that are equally spaced and correlate with glottal pulse periods, but the consonant section shows irregular behaviour that is associated with frication. The formants in the spectrogram are significant and will be discussed along with the pharyngeal approximant in Section 4.

The pharyngeal fricative is common in Semitic languages. However, as mentioned earlier, Butcher and Ahmad (1987) and Laufer (1996) suggest that the voiced pharyngeal segment can also appear as an approximant and a stop, illustrating phonetically, the variable nature of these phonological units.

4. The Voiced Pharyngeal Fricative as an Approximant [ʕ]

As mentioned in Section 3, Laufer (1996) suggests that the voiced pharyngeal approximant is a segment in Arabic, and Bessell (1993) suggests that a pharyngeal approximant is a legitimate segment in Native North American languages. Laryngoscopically, the [ʕ] looks similar to the voiceless pharyngeal fricative but the acoustic data show that it is an approximant rather than a fricative. Figure 7(b), shows approximant characteristics in that, there is no stop portion between the vowels and no trilling or fricative qualities. In a sense, the approximant is unique because it looks almost vowel-like spectrographically. In fact, if only the bottom half of the spectrogram were visible, one would likely confuse the spectrogram with a very long vowel. However, auditorily there is a definite change between the beginning and end of the utterance. This change is visible in the spectrogram above the third formant. The behaviour of the formants above the first three seem to distinguish the consonant from the vowel spectrographically.

This formant behaviour is also seen in the fricative in Figure 7(a). Though this consonant is voiceless, formants occur because the constriction that causes the noise for the pharyngeal fricative is near the vocal folds, which is near the 'normal' source of sound into the vocal tract. Since the noise produced for the fricative has the opportunity to resonate in the whole vocal tract, consequently formants appear in the spectrogram.

What is noteworthy with the formants in Figures 7(a) and (b) is that the fricative and the approximant formants appear to be identical. This suggests that the posture of the vocal tract for both the fricative and the approximant are the same. That is, the vocal tract is in the same position for both the fricative and the approximant, the only difference being the manner of production.

Considering the voiced pharyngeal fricative as an approximant is associated with Semitic languages, as suggested by Laufer (1996), but is argued for acoustically and phonologically by Bessell (1993) in Interior Salish. Bessell promotes \ʕ, ħ\ as fricatives in Arabic since a voiced/voiceless distinction is preserved in nearly all languages that contain pharyngeal fricatives. Phonologically, in Interior Salish, the /ʕ/ is a voiced segment, and the process of glottalization applies to this pharyngeal in a way that is noted for the rest of the resonant series. These two phonological facts from Interior Salish provide the most compelling evidence for this segment as a pharyngeal approximant according to at least one language. The pharyngeal approximant appears phonetically in Arabic but phonologically there is a need for a voiced pharyngeal fricative. Interior Salish provides both phonetic and phonological evidence for the pharyngeal approximant as a segment.

5. Agul

From the acoustic analysis and phonological evidence presented in the previous sections, it can be argued that the pharynx can produce varying manners of articulation. However, one language seems to provide evidence against this. Agul has a range of pharyngeal articulations that, as described in Ladefoged and Maddieson (1996), have both voiced and voiceless pharyngeal fricatives [ʕ] and [ħ] respectively, a voiceless epiglottal fricative [ʜ] and an epiglottal plosive [ʡ]. The fact that there are two fricatives produced past the velum seems to indicate that there is a need for more than one place of articulation past the velum. Although the [ʕ] is classed as a fricative here, it may be an approximant acoustically, similar to the Arabic [ʕ], or it may be a voiced fricative phonologically, if the language requires the segment. However, if the [ʕ] behaves as an approximant the full range of manners, according to the model proposed here, would be represented. That is, there would be a pharyngeal plosive [ʡ], a pharyngeal trill [ʜ], a pharyngeal fricative [ħ] and a pharyngeal approximant [ʕ].

It is not possible to compare the formants spectrographically with the pharyngeal fricative and the epiglottal fricative from the Agul examples in SOWL since the pharyngeal fricative in the, \muħar\ example, is produced after the vowel /u/ that causes the formants to start low for the /u/ vowel, and then change during the course of the consonant to the target position of the following \a\ vowel. This problem refers to an assumption of the IPA, that says "it is possible to describe speech in terms of a sequence of segments, and . . . that each segment can be characterized by an articulatory target" (*JIPA* 1995, p.5). In the case of the pharyngeal fricative in the Agul \muħar\ example, the articulatory target of the pharyngeal consonant is much farther from /u/ than /a/, therefore, the actual consonant timing slot can be described as the transition between /u/ and /a/, however, phonologically the position is used as a pharyngeal consonant. The fact that the acoustic output does not resemble 'ideal' acoustic description of the articulation, illustrates the importance of phonology in classifying acoustic phonetic segments.

Upon investigation of the Agul epiglottal fricative as mentioned in Section 2, it may be more accurate to consider this consonant a pharyngeal trill rather than a fricative. Based on X-ray data, Ladefoged and Maddieson (1996 p.169) suggest that the distinction between epiglottal and pharyngeal may involve constriction at different heights in the pharynx. However, X-ray data rarely show the larynx. It may be that larynx raising, rather than constriction in more than one region in the pharynx, contributes to the trilling and stop qualities described here.

While the X-ray data provide a good illustration of behaviour of the epiglottis itself, the laryngoscope shows how the larynx and aryepiglottic folds can articulate with the epiglottis. Trilling qualities of the aryepiglottic folds would be impossible to see in X-ray examinations but the laryngoscope clearly shows the ability of these folds to trill. However, Traill (1986) notes vibration of the epiglottis in the X-ray data since the epiglottis is blurred during the production of trilled vowels. Although Agul appears to provide evidence for two places of articulation in the pharynx, reconsidering these consonants as varying manners appears more consistent with capabilities of other areas of the vocal tract. More support for this claim may be found by examining the phonological use of these segments in Agul, similar to how Bessell (1992) uses phonological evidence for manners in Native North American languages. In other languages that use pharyngeal consonants, such as Salish and Arabic, it appears that varying manners are adequate.

Conclusion

If the hypothesis of this investigation is accurate, then the epiglottal consonants found under the 'other symbols' on the IPA chart would find a new home under the pharyngeal column of the chart. The epiglottal plosive is really a pharyngeal plosive, the epiglottal fricatives would fit in the 'trill' row and the approximant would require a new symbol to be added to the chart.

From the visual and acoustical facts presented, structures within the pharynx can produce varying manners of articulation and Semitic, Native North American and Caucasian languages, make use of these manners. Bessell (1993) notes the discrepancy in the classification of Arabic pharyngeals that are described acoustically as stops, fricatives and approximants. In this case it is necessary to rely on the phonology to determine the segment's status in the language. This variation in production is reasonable since it is likely that agile and articulate production of speech segments in the pharynx would be difficult and also, there are no visual cues for the listener. This implies that these segments are acquired auditorily and thus subject to more variation. Whether the language uses these pharyngeal segments as a stop, fricative or approximant phonologically may be the best way to determine the status of the segment in the language.

Bessell suggests the need for epiglottals to be "pressed into service" for Native North American languages. However, the phonologies do not seem to suggest the need for an epiglottal region as well as a pharyngeal region. The phonological evidence in Bessell (1992, 1993) suggests a pharyngeal region with varying manners would be adequate and phonetic evidence corroborates this hypothesis.

Moreover, there does not appear to be much evidence to suggest the need for more than one place of articulation in the pharynx. Most phonetic descriptions of the vocal tract do not include epiglottal as a distinct region. Two important points follow from this investigation: First, it is humanly possible to produce varying manners of articulation in the pharynx and second, it is necessary to consider phonological evidence in order to clarify further the use of the pharyngeal segments in the language.

Questions that remain are largely phonological: How does a phonological theory treat the !Xóõ) use of pharyngeal trilling on vowels? How does Agul phonology treat the pharyngeal and epiglottal segments; are they treated as fricatives by the language, or does the epiglottal segment pattern like a trill? Phonetic questions include, what is the active articulator in the pharyngeal region of the vocal tract? How much do the vocal folds affect the aryepiglottic trilling, or vice versa? Also, of importance is the extent to which pharyngeal articulations contribute to the lenis/fortis type of distinction in other languages.

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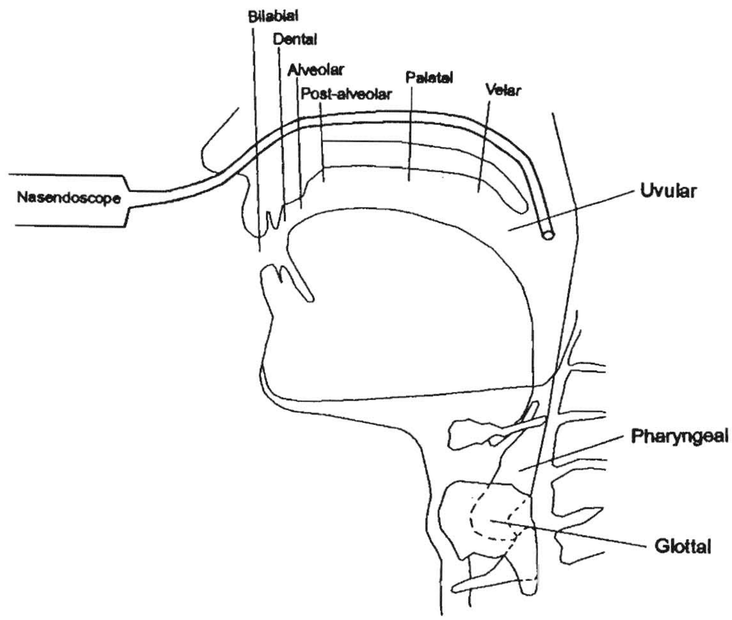


Figure 1. Places of articulation in the vocal tract and the route the nasendoscope takes in order to view the larynx is also shown.

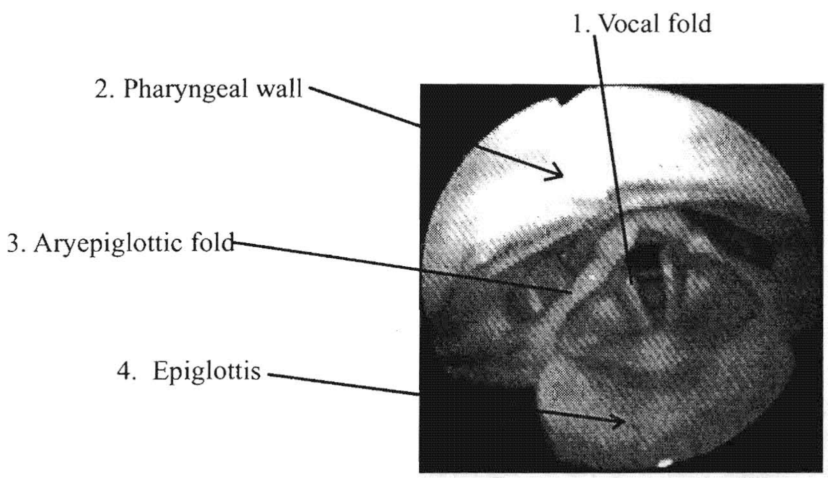


Figure 2. View from the nasendoscope positioned behind the velum shown in Figure 1.

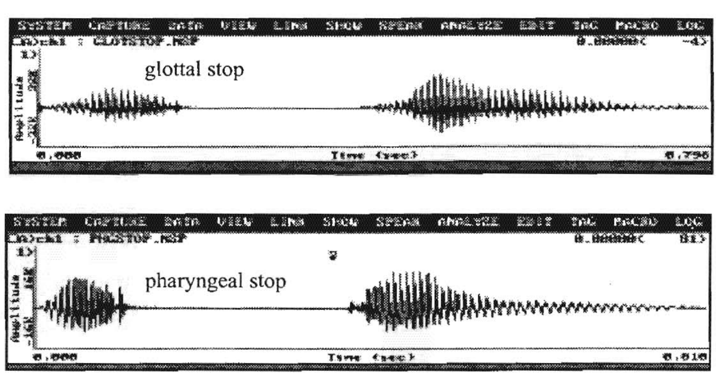
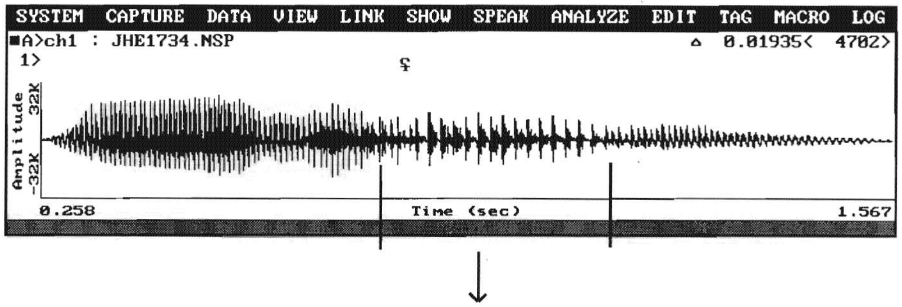


Figure 3. The vowel preceeding the stop in the waveform is shorter in the pharyngeal stop and the stop portion is longer.



0.019s=1/0.019cps=53Hz

Figure 4. Low amplitude segments of the waveform between the marks are measured to show the speed of trilling.

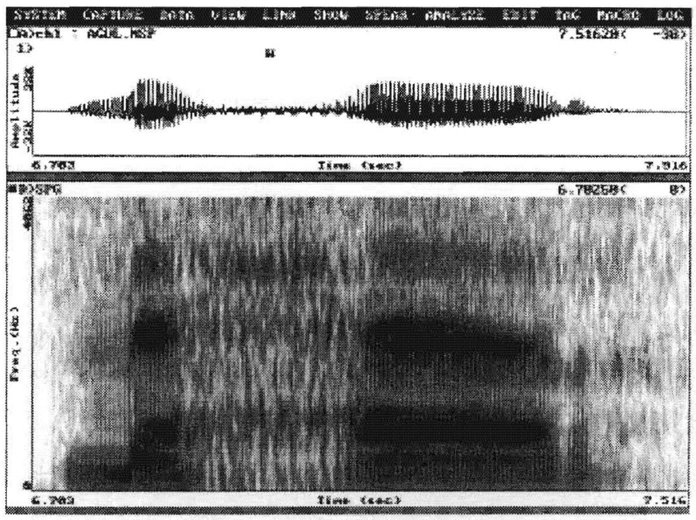


Figure 5. Agul waveform and spectrogram of /mäHär/ that contains a pharyngeal trill. Trilling qualities are seen by the more broad vertical spacing of striations in the spectrogram.

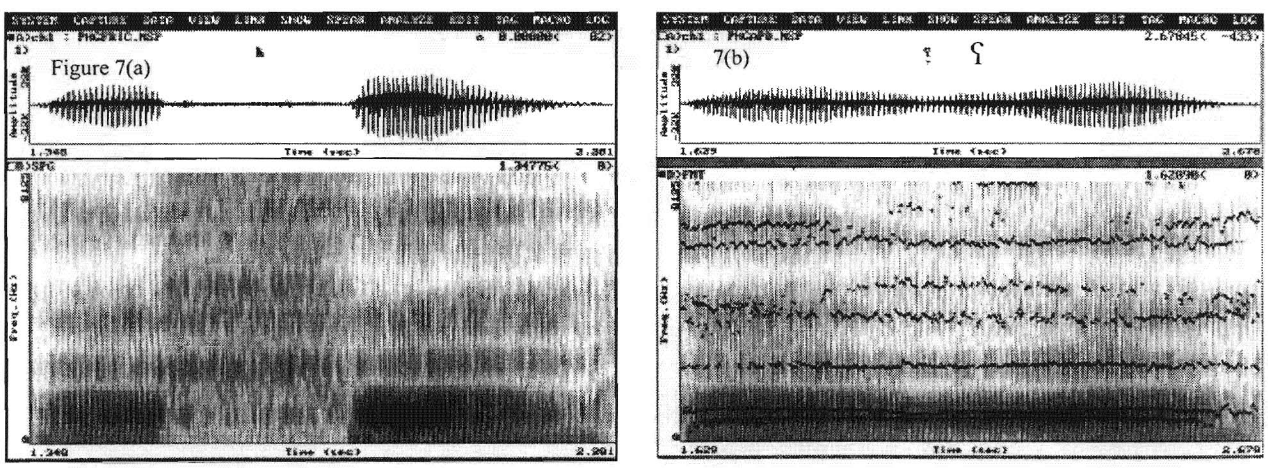


Figure 7(a). The lack of vertical striations in the spectrogram under the consonant symbol, illustrate fricative behaviour. (b) The pharyngeal approximant lacks friction or stop-like behaviour in the spectrogram and waveform.