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VELUM AND EPIGLOTTIS BEHAVIOR DURING THE PRODUCTION OF ARABIC PHARYNGEALS AND LARYNGEALS: A FIBERSCOPIC STUDY.

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ABSTRACT

An experiment was designed to account for the mechanism underlying the production of a set of speech sounds articulated in the back cavity of the vocal tract and to examine the assumption of possible interaction between nasal, pharyngeal and laryngeal articulation. The results obtained from 9 Egyptian speakers of Arabic by using a wide-angle fiberscope revealed that the velopharyngeal port was open during the production of the four pharyngeal consonants i.e. /ʕ, ħ, ɣ,χ/ and the laryngeals /ʔ, h/ for all subjects in the non-nasal context. The degree of opening varies as a function of the constriction location in the pharynx and the height of the following vowel. Moreover, simultaneous active movement of the epiglottis together with a substantial mesial displacement of the lateral phayrngeal walls at the level of the laryngeaopharynx was also observed. The results suggest that the underlying mechanism used to produce pharyngeal segments (contrary to the common knowledge) involves a complex process and not solely retracting the back of the tongue toward the posterior wall as in the case of the pharyngealized (emphatic) consonants and that the possible interaction between nasal, pharyngeal and laryngeal articulation is conditioned by both aerodynamic and mechanical constraints.

I. INTRODUCTION

The languages of the world which utilize the pharynx to produce speech sounds are very few. Arabic has three pairs of such sounds articulated in the back cavity of the vocal tract, the fricatives /ɣ, χ/ which are produced by constricting the upper region of the oropharynx by bringing the back of the tongue in contact with the velum or the uvula; the fricatives /ʕ , ħ/ which have a major constriction in the laryngeopharynx at the level of the second cervical vertebrae; and two laryngeals /ʔ, h/ in which the glottis is their place of articulation. The precise nature of pharyngeal articulation is yet far from being established. It has been thought that the production of /ʕ/ or /ħ/, for instance, is attained merely by pulling the dorsum of the tongue toward the back wall of the pharynx. However, that does not account for the disability of the non-native speaker to produce perceptually intelligible pharyngeal segments.

In addition there is another set of speech sounds articulated in the front cavity vis. /t, d, s, z/ which can be pharyngealized. Pharyngealization is achieved by depressing the blade of the tongue downward and pulling its dorsum backward to approach the posterior pharyngeal wall resulting in larger front cavity due to the concavity of the blade of the tongue and a narrower back cavity due to the retraction of the tongue body. This class of sounds is known in the literature as the Emphatic sounds of Arabic i.e. /*t, d, s, z*/. The emphasis spreads its phonetic information to the adjacent segments (regardless of the syllabic boundaries) in both directions i.e. anticipatory and carry over coarticulation, consequently the quality of surrounding vowels and consonants will be altered. Furthermore a plain pharyngeal segment can occur in emphatic environment. For instance the plain words /ʕæ:z/ and /sæ:ɣ/ can be matched with /ʕɑ:z/and /s ɑ:ɣ/ respectively. Acoustically a typical /ʕ/ is characterised by having the first two formant frequencies at about 740 and 1110 Hz, lack of spectral energy at higher regions in the spectrum and a markedly low F_0. On the other hand the emphatic segment is characterised by an upward shifting of F_1 and a lowered F_2 compared to its plain counterpart [1].

II. MOTIVATION

There are several observations which constituted part of the motivation of the present study:

1) It has been speculated that a pharyngeal consonant can be phonetically developed diachronically to a nasal sound. This process of sound change observed in east Gurage (one of the Semitic Ethiopic languages) seem to pass through two different stages: first the pharyngeal segment is substituted for a laryngeal /ʔ/ or /h/. Then nasalization is induced by the consonant on the following vowel which further decompose into "vowel + nasal consonant". Moreover, it was found that the vowels are nasalized after lower-pharyngeals /ʕ, ħ/ but not after upper pharyngeals /ɣ, χ/ [2]. This can be taken as indication of possible connection between the size of velopharyngeal orifice and the point of constriction along the pharynx.

2) The pharyngeals /ʕ, ħ/ are substituted by /ʔ, x/ respectively among the bilingual community of Greek and Italian origin in Egypt. The same observation holds true also among the non-native speakers of Arabic when they try to pronounce Arabic words containing one or more of the lower-pharyngeal sounds.

3) Children with cleft palate tend to compensate for the inefficient velic closure required during producing speech sounds articulated in the oral cavity, (e.g. /s, ʃ, t, k/) by sounds articulated in the pharynx or the larynx. For instance, it has been demonstrated that the American children with cleft palate tend to substitute the target phoneme /s/ by a sound articulated in the pharynx by pulling the back of the tongue toward the posterior wall of the oropharynx, maybe trying to avoid emission of air through the nasal cavity [3]. On the other hand the terms "pharyngeal stop" [4] and "laryngeal fricative" [5] were used to describe the same phenomenon in the case of Japanese

cleft palate patients. Similar observations were made [6] regarding the Swedish cleft palate children.
4) One of the most common defect among the Egyptian patients of dyslalia (the persistence of isolated phonological errors in a relatively late period of language development) is known as "pharyngeal sigmatism" i.e. the defected segment the patient tend to produce is a nasalalized, pharyngealized (emphatic) [s̃] instead of the oral voiceless dental fricative /s/ [7].
These observations may lead to the following question: What could be the common factor (if any) between the pharyngeal, laryngeal and nasal articulation?. It has been argued that segments articulated at inferior region in the vocal tract (i.e. pharyngeals and laryngeals) will not require the velopharyngeal port to be closed since the point where the air pressure is built up is further back in the vocal tract than that where the oral and nasal cavities are coupled [8].
Data on the articulatory dynamics of the velum has been reported showing that the velar elevation is different for different vowels, and is often related to vowel height or openness; that is , the velum has a higher position for high vowels than that for low vowels [9].
It can be hypothesised, then, that the velic movement will be correlated with the point of constriction along the pharynx and its distance from the glottis
Furthermore the volume increase of the pharyngeal cavity observed during the occlusion period of the voiced stops compared to the voiceless stops in American English was interpreted as a result of a mechanism which will lead to a drop in the supraglottal air-pressure in order to maintain the transglottal pressure differential necessary for the continuation of glottal pulsing through the period of vocal tract occlusion [10]. Most probably activities of the velum is related to the changes in the inter-oral air pressure. It has been reported that greater activity in the levator palatini (which control the elevation of the velum) and sternohyiod muscles would lead to an increase in pharyngeal cavity size [11].
There is substantial evidence that the constriction in the lower pharynx during the production of pharyngeal consonants involves the contraction of more than one muscle. Most of the major works dealing directly or indirectly with pharyngeal articulation have taken for granted that the constriction during the production of pharyngeal consonants is attained solely by the retraction of the root of the tongue towards the posterior pharyngeal wall. However, that does not account for the disability of the non-native speaker to produce perceptually accepted pharyngeal consonants. It seems that pulling the tongue backwards (which is a universal articulatory mechanism) is not enough to create the constriction in the pharynx necessary for the production of various types of pharyngeal articulation in normal cases. One possibility is that activities of the hyoid bone, larynx or the epiglottis cartilage is involved in such mechanism. However, it can be assumed as priori that the constriction in the pharyngeal cavity is executed according to a more complex program than the one-dimensional muscular activity (i.e. retracting the back of the tongue) since it has been demonstrated that the mandible is assigned various degrees of elevation depending on the location of the constriction in the pharyngeal cavities, e.g. /ʕ/ requires more displacement of the lower jaw than that required for /ħ/, /h/, /ɣ/ or /χ/ which all have different points of constriction in the back cavity [12].
On the other hand, the interaction between the velic and pharyngeal activities can be expected, since incomplete closure of the port during the production of non-nasal consonants and vowels may produce coupling between the nasal cavity and the rest of the vocal tract resulting in nasal emission of air (hypernasality), which in turn will effect the acoustic quality of the intended speech segment.
The present study was intended to investigate the articulatory dynamics of the velum and to inspect the shape of the pharynx during the production of a set of speech sounds which occur in the back cavity of the vocal tract.

III. EXPERIMENTAL PROCEDURES

To observe the velic movements as well as pharyngeal activities a wide-angle, Rhino-laryngo fiberscope (Olympus type-B), was used. Two different points were chosen as the most appropriate for the best view. First, the tip of the tube was inserted through the nose of the subject and was pushed through the inferior nasal meatus until it reached a position where the field of the scope displayed both levels of maximal elevation of the velum (e.g. during /s/) and the lowest possible position (rest position), from that position, with the tip of the scope bent downward, it was possible to monitor the top view of the pharyngeal cavity, the lateral walls of the nasopharynx and the nasal surface of the velum at various degrees of elevation.
In another session, the second point of observation was chosen just above the top level of the epiglottis. This position made it possible to observe the glottis, epiglottis and the lateral walls of the laryngeopharynx as well as the root of the tongue.
Nine Egyptian male-speakers were used to provide the test material. Each subject was asked to read a total of 92 words representing various type of pharyngeal, laryngeal and nasal articulation in three vowel environments i.e. /i, u, æ/.
The words chosen to be the speech material in the present experiment were selected to reflect the articulatory dynamics of the back cavity of the vocal tract and to represent various points of constriction in the upper and the lower pharynx (see table below):

C_1 V V . Cp V .
C_1 V . Cp V V . C2 V .
C_1 V Cp . Cp V C_2 .
C_1 V C_N Cp .

C_1 = plain or pharyngealized
Cp = pharyngeal or laryngeal
C_N = nasal consonant
V = / i / , / æ / or / u /
C_2 = any oral consonant.

The pictures obtained from each subject via the fiberoptic objective lens were censored by a video camera and were recorded on a number of VHS-video tapes. A "timer clock" showing the hours, minutes, seconds and every hundredth of a second was recorded on the films in order to be able to synchronize the picture frames with the audio signals. A 4500 Hz pure-tone signal was recorded on the audio channel of the video-tape signalling the onset of each minute of speech.
A thorough visual and auditory inspection for the video tapes was made, then a hard copy of a selected number of frames was obtained by using a video copy-printer "Mitsubishi P-60B". Frame by frame scanning was made

using a " motion picture analyzer". This picture analyzer made it possible to scan the film in a slow and precise way so that the selected frame was frozen at a point well corresponding to the phonetic segment in question. Velar height was measured in terms of the distance between two points along the vertical axis drawn on a grid at the centre of the image for each frame, the highest elevated position the velum can reach for each speaker, e.g. during the production of the sound /s/, was considered as the highest point on that axis, while the lowest point was that which the velum assumes during the rest position, i.e. quiet breathing.
The displacement of the lateral walls of the nasopharynx toward the midsagital plane was measured on a central axis perpendicular to vertical axis. Two points were taken to represent the side-to-side distance.
Velar height was plotted on an arbitrary scale as a function of time along each utterance. The curves were aligned at the onset of the pharyngeal segment.
The audio signals representing the speech material was digitalized via an A/D converter, and then stored on the hard disk of a computer in the form of files. Each file begins and ends with the pure-tone "pip" signal. The time interval between each "pip" was 60 seconds which corresponds to an equal interval indicated by the timer on the video film. Wide-band spectrograms were made for each test word using a computer software package. By comparing the spectrograms with reference to the Time-onset (zero-time) of the speech file and the timer-reading appearing on the hard copy from the video-printer (or directly on the screen), the frames corresponding to each phonetic segment were determined.

IV. RESULTS AND DISCUSSION

Data inspection revealed that /ʕ, ħ, ʔ, h/ are produced with an open velopharyngeal port in the non-nasal context for all subjects. The degree of velar height varies as a function of the vowel context and the point of the constriction located in the pharynx and it reflects a limited degree of inter-speaker variability (figure 1). The emphatic consonants did not show any significant effect on the velic opening than that displayed during the non-emphatic oral articulation.
Further inspection of the data showed that the epiglottis moves actively and independen from the tongue movement during the production of those segments which have a major constriction located in the inferior region of the pharynx i.e. /ʕ, ħ/ (figure 2). The extent of this movement is less for upper pharyngeals /ɣ, χ/. For instance during /ʕ/, the epiglottis leans on the top of the arytinoied cartilages leaving a narrow passage between the edge of the epiglottis and the posterior pharyngeal wall for the air to escape. It should be noted that the maximum lowering of the velum occurs always at the point of maximum downward-displacement of the epiglottis which correspond to the midpoint of the pharyngeal segment on the spectrogram.
The interesting finding was that the lateral pharyngeal walls at the level of laryngeopharynx displayed a substantial misial displacement concomitant with the tilting of the epiglottis. Furthermore, the arytenoides were observed to move upward and forward, hence, relaxing the vocal folds which might explain why /ʕ/ is characterized by a markedly low F_0. During /ħ/ the vocal folds were brought together at the anterior angle and wide apart at the posterior base, the resultant shape was more like an equilateral triangle. The shape the glottis assumed during /ʕ, ħ/ indicates that a major constriction occurs in the larynx itself.
Based on the findings obtained from the present experiment, a relation can be observed between the constriction location across various points in the pharynx and the degree of velic opening since it has been shown in the present investigation that the velum assumes different degrees of elevation depending on the location of the constriction in the pharynx as well as on vowel height. In other words, those segments which have a constriction located at a superior level in the pharynx, e.g. /ɣ, χ/ display a greater amount of velar height than those segments articulated further down in the pharynx, e.g. /ʕ, ħ ,ʔ , h/ (cf. Fig. 1). It can be suggested that segments which have a constriction at inferior regions in the pharynx will have more nasal coupling than those in superior regions, hence, they may reflect a greater degree of nasalization. However, such conclusion can not be made until extensive acoustic verification has been made.
The nature of the interaction between nasal and pharyngeal articulation can be realized when taking into consideration the connection between the soft palate and the lateral and posterior pharyngeal walls in terms of the activities of the palatopharyngeous muscle. This muscle acts to decrease the distance between the pillars of the "isthmus of fauces" (the port through which the oral cavity communicates with the nasal and pharyngeal cavities), accordingly the velum is pulled down. The force used to prevent the velum to be raised to its upper most level, as the articulatory gesture (being a non-nasal segment) requires, can be best described as a sort of mechanical constraint leading to a coarticulatory effect, that is, the velum is pulled down due to the anatomical connection with the pharyngeal muscles. In addition, that the jaw was found to be assigned different degrees of elevation as a function of constriction location in the upper and lower pharynx, and that this location is maintained even during the vowel following the pharyngeal segment [12], can also contribute to the mechanical constraints acting on the velic movements, since the movement of the jaw and the tongue (being carried by the mandible) will effect the amount of the inter-oral air-pressure which in turn will alter the state of the velum.
On the other hand, the aerodynamic requirements, necessary for causing the velopharyngeal port to be closed, will be less severe when the constriction occurs in the lower pharynx, since lowering of the velum to a certain

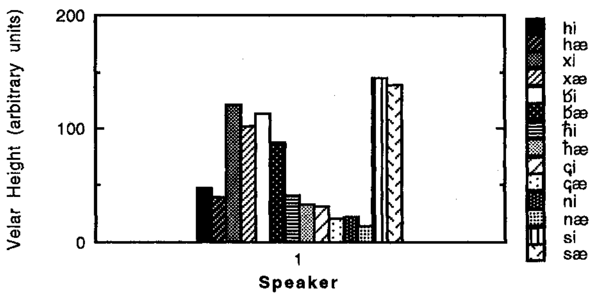

Figure (1) : Histogram representing velar-height for one speaker during various consonants in two vowel environments /i, æ/. The measurements, which were plotted on arbitrary scale, represent the mid-point of each consonant duration.

degree will not effect the amount of air-pressure associated with constricting inferior regions in the vocal tract and which is necessary for building up the turbulent noise behind the stricture in the pharynx.
It can be argued, then, that the possible interaction between the nasal, pharyngeal and laryngeal articulation is conditioned by both aerodynamic and mechanical constraints.

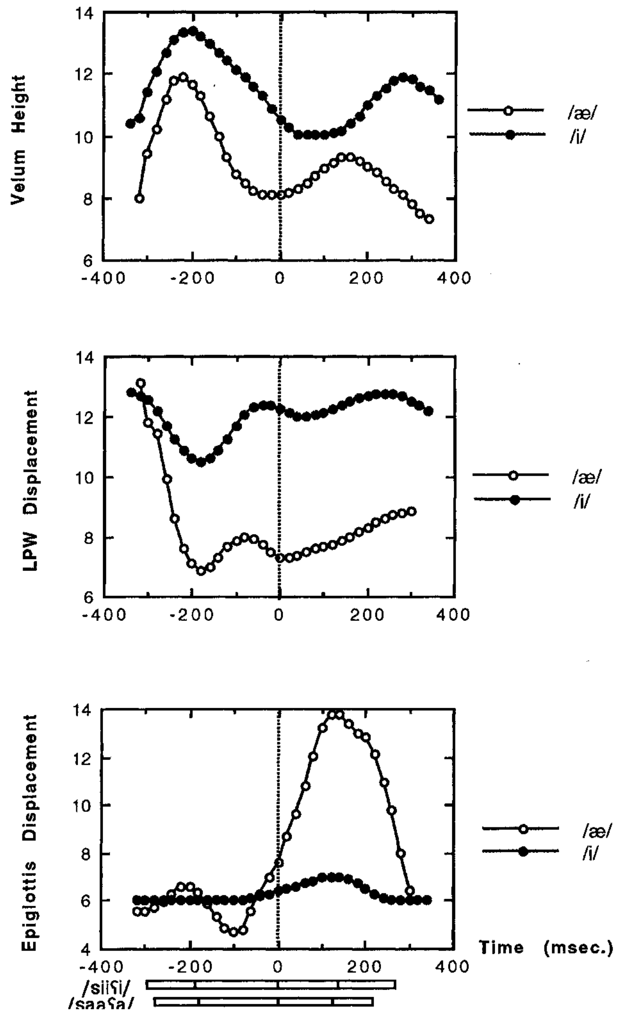

Figure (2) : Tracing of various displacement of the velum (top graph), lateral pharyngeal walls at the level of nasopharynx (middle graph) and the epiglottis (bottom graph) during the production of the minimal pairs /siiʕi/ vs. /sææʕæ/ uttered by speaker 5. All curves are aligned to the onset of the pharyngeal segment /ʕ/ and plotted on arbitrary scale.

V. CONCLUSION

The present study showed that the pharyngeal and laryngeal segments are produced with an open velopharyngeal port in the non-nasal context, though not as much as in the case of nasal segments. The degree of velar height during the production of this class of speech sounds varies as a function of the constriction location in the back cavity of the vocal tract as well as the vowel height. The active involvement of the epiglottis in the production of such segments can be seen as a factor which determine the extend of the velic movement. The lateral pharyngeal walls also has been shown to be actively involved in shaping the back cavity and the size of the constriction in the pharynx. The temporal patterns controlling such movements were found to be significantly interacted and synchronized, one suggestion the present data can offer for the development of an articulatory model of speech.

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