MRI INVESTIGATION OF ARABIC GUTTURALS

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ABSTRACT

Five native speakers of Assiri Arabic were imaged using magnetic resonance imaging (MRI) during their production of gutturals. These Arabic back consonants are characterized by articulation in the pharyngeal region that extends between uvular and larynx. The aim of this experiment is to examine pharyngeal width and larynx height in production of these consonants and observe if these two parameters provide an articulatory basis for classifying gutturals into a natural class in the feature geometry.

Keywords: gutturals, magnetic resonance imaging (MRI), Arabic, pharyngeals, articulatory feature

1. INTRODUCTION

Arabic gutturals are a group of consonants that share the pharynx as a place of articulation. They are classified into three subgroups:

Glottals
[ʔ] &[h] as in ʔum & hum "mother", "they"
Pharyngeals
[ʕ] &[ħ] as in ʕali & ħali "high" , "sweet"
Uvulars
[χ]&[ʁ] as in χali & ʁali "empty" , "expensive"

Since they share the pharyngeal cavity as a place of articulation, [6] suggests granting gutturals the feature [pharyngeal] (where its place feature is broadly interpreted to extend to constriction in the pharynx and larynx). This hypothesis is built upon some phonological evidence that demonstrate similarity between gutturals in Arabic. This hypothesis was previously investigated using techniques such as X-ray [5]. Also, they were investigated using endoscopy [7] and [2-4]. However these consonants have not been previously investigated using MRI.

Pharyngeal width and larynx height are considered two parameters in the articulation back consonants. The aim of this experiment is to examine the role of pharyngeal constriction and laryngeal height in the production of gutturals and observe if these two parameters provide an articulatory basis for classifying gutturals into a natural class [6]. Arabic guttural consonants do not have a single common articulatory feature identifying them as a natural class except sharing the same region of articulation, the pharynx. Although, the glottal stop [ʔ] and fricative [h] lack constriction in this region, yet they are also classified as guttural ([6, 7]).

This experiment will identify pharyngeal constriction by measuring change in pharyngeal width during articulation of each consonant.

2. METHOD

2.1. Subjects

Five subjects participated in the experiment. Subjects were not scanned in the same session. The first subject (the first author) was scanned in a trial session which was used to establish the protocol and measurement procedures while the other four subjects were scanned afterward in Wesley hospital in Brisbane, Australia. All of the subjects lived the majority of their lives in Saudi Arabia. They had moved to Brisbane where they resided for 1-2 years at the time when this experiment was conducted. Subjects' age range was between 25-35 years. All subjects were native speakers of Arabic and spoke the Assiri dialect which is spoken in the southern region of Saudi Arabia.

2.2. Stimuli

The target sounds to be examined in this study are the set of gutturals; [ʔ] [h], [ħ], [ʕ], [χ] and [ʁ]. Also, oral consonants [s], [t], [ð] and [d] were tested to provide comparative measurements between gutturals and this group of coronal consonants. The reason for choosing this group of oral consonants is that they have equivalent emphatics that have secondary articulation in the pharyngeal region while these plain consonants lack this constriction and are the most appropriate oral consonants that can be compared with gutturals.

2.3. Apparatus

The static MR images were obtained using a Siemens 2.0 T Signa magnet; 6-mm thickness sagittal slices were captured using the fast spin-echo technique with the following parameters: time repetition (TR) = 52 ms, time echo (TE= 4.8 ms, Flip Angle (FA) = 20 degree, field of view (FOV)= 200 Phase: 81.3 and Bandwidth = 176 hx /pixel. Acquisition times were 11 seconds and the number of slices was 6 per acquisition. This relatively long acquisition time represents a practical limitation on the use of static MRI in speech research.

The static MRI was chosen for this experiment rather the dynamic one for couple of reasons. The main one is that the dynamic MRI is composed of single images from different times of the production of a sound, and these images are put together to make an animation. Since the individual images have low quality resolution, dynamic MRI cannot be used to find exact dimensions of pharyngeal width and larynx height. Additionally, dynamic MRI was not available at the University of Queensland at the time this study was conducted.

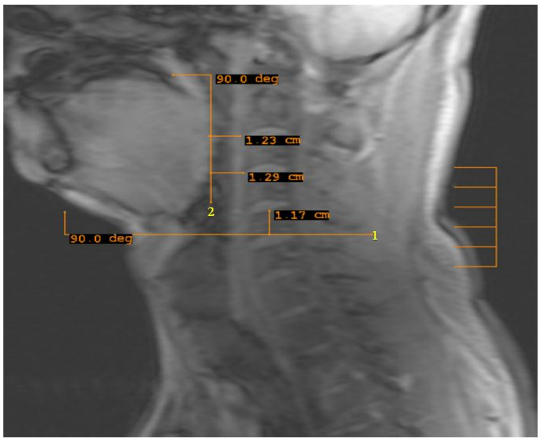
2.4. Method of MRI image capture and data analysis

In this experiment, 11 seconds was the acquisition time to record 6 images, 1.83 second per image. In an effort to overcome the difficulty caused by long capture times required for static MRI imaging, all subjects were trained to maintain a static target posture for the production of each sound. Target sounds were printed and distributed among the subjects. During production of sounds, subjects were trained to hold the initial position of each target sound for 11 seconds which is the necessary time for acquiring images. These training sessions were repeated until the investigators became sure that all subjects were aware of what they were going to do during the time of MRI scanning.

In this experiment, we are concerned with two variables: larynx height and pharyngeal constriction. As shown in Figure 1, laryngeal height is determined by an extended horizontal line which was drawn on the top surface of the arytenoid cartilage. This horizontal line intersected a vertical line linking two stable reference points. The first stable reference point is on the upper surface of the fifth vertebra and the second point is specified on the lower surface of the same vertebra. The vertical movement of the larynx was observed by measuring the change of distance between the two vertebral reference points and the horizontal line. This change of distance was labeled *Laryngeal height*. Elevated laryngeal level was characterized with a positive sign while a depressed laryngeal level was characterized with a negative sign.

The second variable that was observed from the MRI images was pharyngeal width on two levels; at the level of tongue root (*pharyngeal width*) and at the level of epiglottis (*epiglottal width*). In order to measure these parameters, two reference points were identified on the front surfaces of the second and third vertebrae, exactly above the vertebral cartilages that are located on the underside of each the two vertebrae. Change in pharyngeal width can be calculated from horizontal movement of the tongue root and the epiglottis. In addition to these fixed reference points, the movement of the tongue root and the epiglottis were determined by drawing vertical lines on their back surfaces. The distance between these vertical lines and the two front vertebral reference points can be measured during 'rest position' (supine position in MRI without speech) of each subject and during production of target consonants.

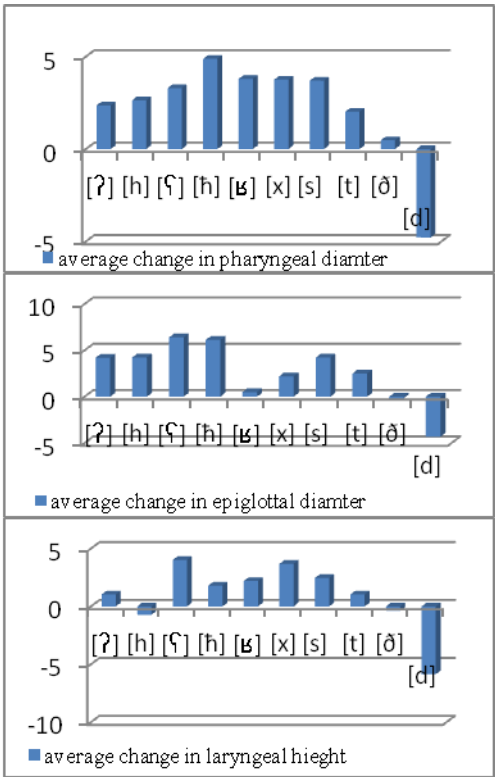
Figure 1: Measuring larynx height and pharyngeal constriction width: 1. A long horizontal line represents larynx height in a straight level; a short vertical line represents the total distance between two reference points. 2. A long vertical line is used to measure pharyngeal width during the horizontal movement of the tongue root.



3. RESULTS

Results were plotted in Figure 2, which shows in millimeters the average change of pharyngeal width, epiglottal width and laryngeal height with respect to the resting position of the articulators of each subject. To evaluate the three parameters - pharyngeal width, epiglottal width and laryngeal height - a series of two-way ANOVAs were conducted. One aim of these ANOVAs was to investigate whether these parameters have a significant role in distinguishing gutturals from plain consonants or not. Also, the subject factor was investigated for individual differences and, lastly, the interaction between the three parameters and the Subject factor was examined to observe if there were any interaction effects involved.

Figure 2: Changes (shown in millimeters) in pharyngeal width, epiglottal width and laryngeal height. Minimized pharyngeal width and elevated laryngeal level was granted positive value while widened pharyngeal and depressed laryngeal level was granted negative value.

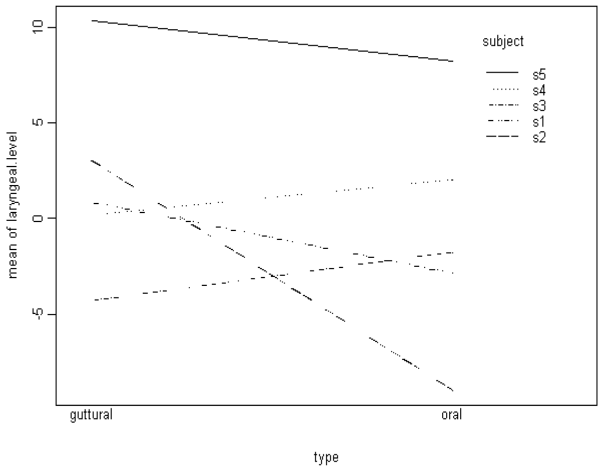


The first ANOVA was carried out to investigate the role of subject and pharyngeal width in differentiating between gutturals and oral plain consonants. The results show the subject factor is significant (p = 0.04), and that pharyngeal width has a highly significant role in distinguishing gutturals from plain consonants (p = 0.0003). Although there is a significant main effect of subject, its magnitude is considered small compared with the high significant role of pharyngeal width. There was no interaction between subject and pharyngeal width (p = 0.56).

A second ANOVA was conducted to investigate the role of subject and epiglottal width in differentiating these two types of consonants. The results showed the subject factor was significant (p = 0.036) there was a highly significant main effect for epiglottal width (p = 0.001). The significant effect for subject is considered small when compared with the significant role of epiglottal width. There was no interaction between subject and epiglottal width (p = 0.90).

The third ANOVA was conducted to investigate subject and laryngeal level. This two-way ANOVA also investigated whether there was any interaction between them. Here, it can be seen that the subject factor was highly significant (p = 0.00000019). This finding may be ascribed to individual differences between subjects who differ physiologically so that the horizontal levels of the larynx naturally are different. Larynx level is also significant (p = 0.03), however, this effect is small in comparison with the highly significant effect of subject. The ANOVA results show a significant interaction between subject and the laryngeal (p = 0.003). This interaction was plotted in Figure 3.

Figure 3: Interaction between subject factor and laryngeal level during production of gutturals and plains (oral consonants).



To further verify the ANOVA results, post-hoc tests were carried out. These tests indicated that, of the three parameters, pharyngeal width plays the most significant role in distinguishing the gutturals (p = 0.0006). Epiglottal width is also significant, however it is less significant pharyngeal width t (p = 0.0019); and laryngeal level is not significant (p = 0.1573).

4. DISCUSSION

Generally, it can be said that pharyngeal and epiglottal widths are distinctive articulatory gestures of gutturals. Conversely, laryngeal height is a gesture that does not correlate directly with the production of gutturals.

During the production of the glottal stop [ʔ] and fricative [h], there is no clear constriction point in the pharynx even though they are produced with a narrower pharyngeal width and retracted epiglottis. These findings support the results of previous studies by [2, 4] and [7] which found that the oral consonants, [s] and [k], are produced with a narrower pharyngeal width than the glottal consonants [ʔ] and [h]. In contrast, these studies do not agree with [5] who explained retraction of the epiglottis towards the pharyngeal wall observed in one X-ray image as a constriction formed to produce the glottal stop [ʔ]. This claim is perhaps supported by observations of a similar retraction of the epiglottis toward the pharyngeal wall during the production of the plain alveolar fricative [s].

A raised larynx is a noticeable gesture during the production of pharyngeals, as previously observed in studies by [1] and [7]. The pharyngeal approximant [ʕ] is characterized by the maximum elevated larynx among the group of gutturals while the pharyngeal fricative [ħ] is characterized with the maximum pharyngeal constriction.

The voiced uvular fricative [ʁ] and the voiceless uvular fricative [χ] are produced with constriction in the uvular region due to retraction of the tongue dorsum towards the uvula. The constriction in this region is accompanied by minimized pharyngeal width. Both uvulars [ʁ] and [χ] are articulated with almost equal pharyngeal width; however the uvular [χ] is produced with more retracted epiglottis and higher laryngeal settings.

MRI data show that laryngeal height does not correlate directly with production of gutturals; however it relates mostly to the physiological natural level of the laryngeal structure Figure 3. At the same time, the average findings of MRI data agree with Esling's findings ([2-4]) which suggest that pharyngealization is associated with larynx height in the articulation of pharyngeal approximants and stops while a lowered larynx is associated with in production of the pharyngeal fricative. Esling suggests that larynx height controls the manner of articulation of back consonants by permitting the epiglottis to move differently to the posterior wall of the pharynx.

5. CONCLUSION

To conclude, it can be said that group of gutturals, with the exception of the glottals, have different constrictions in the pharyngeal region. Pharyngeals have constriction in the lower part of the pharynx; uvulars have constriction in the upper part of the pharynx. Furthermore, the laryngeal level is highly influenced by the natural physiological position of individual subjects. At the same time, Average findings of MRI suggest that laryngeal height is a variable that controls the manner of articulation of gutturals; however this articulatory feature cannot be considered as a phonetic basis to distinguish gutturals as a natural class of sounds.

6. REFERENCES

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