The Articulatory and acoustics Effects of Pharyngeal Consonants on Adjacent Vowels in Arabic Language

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Abstract

This study uses physiological and acoustic data from a Moroccan Arabic male speaker to examine the articulations involved in the production of pharyngeal sounds and their effects on the adjacent vowels. It is known that vowel quality varies depending on the place or the manner of articulation of a preceding or a succeeding consonant; the coarticulation process affects considerably the production of phonemes in sequence. The present study shows that the larynx vertical movement gesture for pharyngeal consonants in Moroccan Arabic overlaps as coarticulation on adjacent vowels. The obtained results give us an overview of the larynx activity during the production of the three short vowels /a, i, u/ in an environment where the larynx rises relative to the rest position. The consequences of change in the vertical dimension of the pharynx due to the larynx raising on vowel quality are also explored. The coarticulatory effects will be assessed through the frequency modifications of F1, F2, F3, F4 and the variation in the distance F2-F1.

1 Introduction

One of the major difficulties in studying speech production is the problem of observing how speakers coordinate various articulatory movements, i.e. the aspects that connect physiology and speech production. In a continuous speech, a set of coordinative structures is involved to organize the execution of such stereotypes as the length of the vocal tract and laryngeal adjustment. The larynx is composed of several muscles responsible for his vertical movements also for fixing it to neighbouring organs (Marchal, 2010), which makes the adjustment of the laryngeal activity a complex task. It is situated under the hyoid bone and the tongue, it follows their movements. The Larynx height parameter is reported differently in different studies for different sounds, it contributes significantly to pharyngeal volume and sound quality in Arabic gutturals. Interestingly, a number of studies have observed substantial elevation of the larynx during the articulation of the Arabic pharyngeal consonants /ħ, ʕ/.The pharyngeal consonants have a primary place of articulation in the pharynx region of the vocal tract (McCarthy, 1994). The literature describes pharyngeal consonants as segments exerting fairly strong coarticulatory effects on their adjacent context. That is the reason that we deal with pharyngeal consonants in the present work, knowing that each regional dialects of Arabic have distinct coarticulatory and pronunciation patterns (Embarki, 2007; Ghazali, 2002), it is most appropriate to examine coarticulatory patterns within a contemporary vernacular Arabic dialect. This paper describes a physiological and acoustic study of the pharyngeal sounds of Moroccan Arabic (MA) and the articulatory and acoustic effects of these sounds on neighbouring vowels. The aims are to investigate the main articulatory attributes that correspond to the pharyngeal feature in MA, mainly the larynx activity. Measure the coarticulatory effects that pharyngeal consonants exert on adjacent vowels in the sequences, identify evidence for coarticulation principles of pharyngeal consonants and adjacent vowels. A number of previous studies have dealt with the acoustic consequences of the change in pharyngeal length on vowel production especially the lowering of the larynx (Marchal, 2010), but the lack of precision with respect to the vertical movement of the larynx has leads us to quantify the displacement of the larynx during vowel production in different contexts, especially in cases where the larynx rises considerably as in pharyngeal consonants production. In addition, the adjustment of the larynx height parameter in the articulatory model is essential for the production of vowels with good accuracy. No previous studies that have explicitly examined larynx activity associated with the vowels in the pharyngeal environment, our study is a more comprehensive investigation that shed light on the larynx activity during the production of the three MA short vowels in pharyngeal neighbouring, including articulatory and acoustic components. In Arabic, the consonants transcribed as /ħ, ʕ/ have been conventionally categorized as pharyngeal, suggesting a place of articulation at the pharyngeal wall. Furthermore, the default laryngeal setting for these sounds is a raised larynx position. Two dimensions of movement anterior posterior and raising lowering of the larynx are adequate to label pharyngeal sound (Esling, 1996). A number of experimental studies have focused on the production of Arabic pharyngeal consonants in various dialects using physiological methods such as x-ray images or fiberscopes video monitoring (Laufer, 1988; Djeradi, 2006). However, a few studies have presented measurements bearing on the phonatory articulators' movements of Arabic back consonants and their influence on the adjacent vowels articulation. According to the lateral x-rays tracings of the vocal tract outlines for one Lebanese speaker (Delattre, 1971) and one Tunisian speaker (Ghazeli, 1977), two points of constriction were observed, one was at the hard palate (about 6 centimetre from the lips) while the other was located at the level of the epiglottis (about 3-4 centimetre above the glottis). Also, it was observed that the larynx was raised at about 9 mm relative to the default position (Ghazeli, 1977). The measurement of the elevation of the larynx during Arabic pharyngeal consonants in Alwan study is 0.7cm (Alwan, 1989). Knowing that the coarticulation process affects considerably the production of phonemes in sequence and the coarticulatory effects of neighboring segments on each other can operate in both directions. The intergestural timing relations exist between adjacent vowels, between vowels and preceding and following consonants, and between consonants in sequences. Byrd (1994, 1996) points out that these relationships allow gestures to overlap spatially and temporally resulting in an acoustic output which varies according to the behaviour of active gestures (Byrd, 1996, 1994). Thus the coarticulation has been viewed consistently as an expansion of traits. These are not only the result of the mechanical limitation of the articulators, they also depend on phonological constraints specific to the linguistic system, often attributed to the consonantal and vowel inventory of the system. The phonological specificities of the consonantal system explain the limitation of the transconsonant coarticulation. The motor and acoustic aspects of coarticulation are subjects of numerous studies, thus, many studies on the acoustic consequences of change in the vertical dimension of the pharynx have been carried out. The raising or lowering of the larynx alters the length of the pharyngeal cavity and this alteration plays an important part in determining voice quality (Marchal, 2010). McCarthy (1994) states that the main effect of pharyngeal consonant coarticulation that has been observed is an elevation of the first formant F1 by about 100 Hz, as measured in steady-state portions of an adjacent vowel(McCarthy, 1994), similar results were reported by (Al-Ani, 1970; Butcher, 1987; Zawaydeh, 1999). Alwan (1989) found with a synthesized speech that the primary perceptual correlate to coarticulation on a vowel for a pharyngeal segment was a high F1 and a low F2, she found that listeners prefer an (F2-F1) value that is lower for pharyngeal and the optimal pharyngeal candidate has an F2 close to F1. Stevens (1972) suggests that a high F1 and a low F2 of pharyngeal together form a strong spectral region, which contributes to the stability of these segments. Bin-Muqbil (2006) suggested that F2 values in vowels /i/, /a/ and /u/ after pharyngeal consonants are not significantly different than those after plain consonants in almost all cases(Bin-Muqbil, 2006). Other studies indicated some variation in F2 values after pharyngeal consonants(Al-Ani, 1970; Butcher, 1987; Zawaydeh, 1999; Ghazeli, 1977). Marchal (2010), stated that the net result of the larynx lowering is to bring F3 closer to F4 (Marchal, 2010). This phenomenon of the reduced distance between F3 and F4 has also been observed in the singing voice by Sundberg (2003), who considers this narrowing of the difference between the two upper formants as the principal characteristic of sung vowels when they are produced with a lowered larynx (Sundburg, 2003). In our study, the way of envisaging how the speaker coordinates his articulatory movement is to situate the process in a physiological theory of speech production. Thus, an articulatory model is built from cineradiographic images of a sagittal view of a Moroccan male speaker vocal tract, in order to approach the geometry of the speaker vocal tract. The present study focused on looking into issues related to the coarticulation process in order to adjust the larynx height parameter in articulatory models and evenly quantify the coarticulatory effects that pharyngeal consonants exerts on adjacent vowels in the sequences to identify evidence for coarticulation principles of pharyngeal consonants and adjacent vowels. Based on x-ray images of the vocal tract, we examined the vertical larynx movement, the hyoid bone location, the constriction opening and its location during the production of the MA pharyngeal /ħ, ʕ/ consonants, and we explored the behaviour of these articulations during the production of the adjacent vowels; the coarticulatory effect of these sounds on neighboring vowels in order to identify mainly the extreme larynx position during the production of the vowels in the pharyngeal environment.

2 Materials and Methods

The data used in this study were taken from a data base (DOnnées Cinéradiographiques VAlorisées et recherches sur la Coarticulation, Inversion et évaluation de Modéles
physiques) (DOCVACIM) (Sock, 2011). DOCVACIM database makes available a set of multilingual and multimedia data on speech production containing cineradiographic images of the vocal tract and acoustic signals. The Phonetics Institute of Strasbourg (IPS), the Grenoble Institute of Speech Communication and the LORIA in Nancy share some of the best x-ray movies on speech production that were made at the IPS, dealing with linguistic issues in languages spoken in Europe, in Africa, in Asia and in Latin America. The radiographic film used in this study consists of 2700 vocal tract x-ray images of a native Moroccan Arabic adult male speaker, and the acoustic data consists of 60 sentences in Moroccan Arabic dialect. For this study, we processed the images that correspond to the production of Arabic vowels adjacent to pharyngeal consonants. These articulatory data allowed us to extract combinations of articulators for this phonetic type. In the following section, we presented the tools allowing their analyses and their application in the context of speech production, and articulatory modelling approaches.

2.1 Treatment of Acoustic Data

The acoustic database consists of 60 sentences uttering by an adult male speaker in Moroccan Arabic dialect which is the L1 of the speaker. In this study we selected sequences that contain the pharyngeal consonants, we treated seventeen tokens of / ʕ/, eight tokens of /ħ/, and we have also treated sentences from the corpus containing vowels in pharyngeal neighboring; fifteen tokens of the three vowels distributed as follow: ten tokens of /a/, three tokens of /i/ and two tokens of /u/. On the other hand, we processed sequences containing vowels adjacent to plain coronal consonants: twenty-two tokens of /a/, twenty tokens of /u/ and thirteen tokens of /i/. We used the software Praat to segment the sentences into phonemes and also for the phonetic annotation (shown in Fig. 1), the length of each sentence is measured and also the duration of the entire sequence. After segmentation, we synchronized each phone with the corresponding x-ray images of the speaker vocal tract. Thus, for each phoneme, we have the corresponding vocal tract x-ray images, and then we processed the vocal tract x-ray images corresponding to each phoneme.

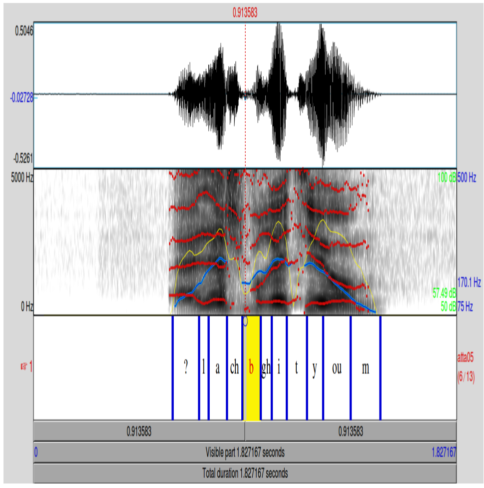

Figure 1: Segmentation of the phrase / ʕla ʃ/ /bɣit//yum/.

2.2 Treatment of X-Ray Images

X-ray images cannot be used directly, but manual, automatic or semi-automatic processing is necessary (Laprie, 2014). The contours of the articulators involved during speech production are tracked (tracking provides the displacement parameters, i.e. rotation and translation). The automatic tracking of bone structures is carried out, semiautomatic tracking for slightly overlapping organs, and finally manual delineation of the tongue. The contours are annotated and exploited for direct measurement of the articulators' displacement. In this work, we have drawn the main articulator contours, particularly those of the tongue, lower and upper lips, the larynx, the glottis, the jaw, the hard palate and the hyoid bone. Before the delineation of the phonatory organs contours a phonetic annotations and synchronization of the annotation is carried out via visual events which produce an acoustic event simultaneously. Prototypes of the processed vocal tract x-ray images are given in Figure 2.

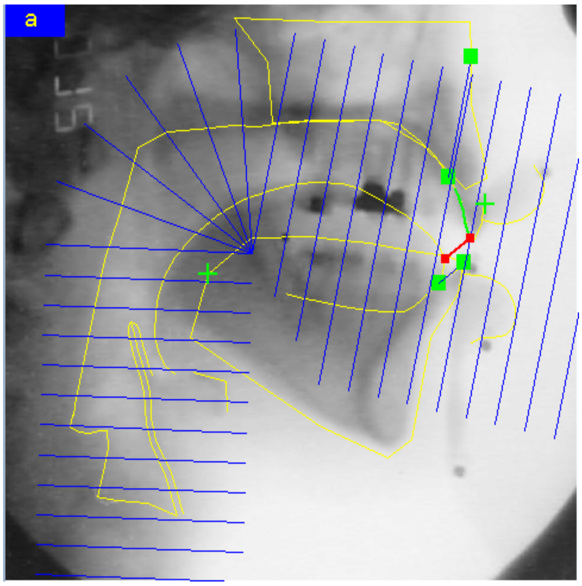

Figure 2: Prototype of the processed x-ray image (the grid, the articulators contours, the annotation in the top left of the image) during the production of the vowel /a/.

2.3 Measurement of the Displacement of the Phonatory Organs

The method of measurement of the displacement of the phonatory organs is based on an angular reference (semi-polar coordinates). Since the vocal tract configurations are different for each speaker, it is necessary to make an adapted grid for our subject. The measurement grid operates in relation to an orthonormal basis that is drawn beforehand on tracing paper (Bouarourou, 2014). This method is used in the analysis of numerous data collected on different subjects. The advantage of using this method is in the fact that it allows us to observe the maximum displacements: the larynx, the hyoid bone, the lips aperture and protrusion, the displacement of the tongue, the mandible, etc. In our study, we focused on the measurements of the larynx center position, the constriction opening, the constriction location and the hyoid bone position, knowing that these components are the effective gestures for producing the pharyngeal consonants as mentioned above.

Consonants	/ʕ/	/ħ/
HB raising (cm)	0.724 SD (0.297)	0.597 SD (0.283)
LC raising (cm)	0.872 SD (0.205)	1.644 SD (0.383)
co (cm)	1.157 SD (0.329)	1.078 SD (0.118)
cl (cm)	13.758 SD (0.209)	13.408 SD (0.349)

Table 1: The average values with (SD) regarding the measures of the elevation of the hyoid bone and the larynx center, the constriction opening and location during the production of the pharyngeal /ʕ/ and / ħ/

3 Results and Discussions

Table 1 summarizes the elevation of the hyoid bone (HB) and the larynx center (LC), the constriction opening (co) and the constriction location (cl)during the production of the pharyngeal /ħ, ʕ/. We focused on the vertical movement of the LC and the HB relative to the rest position, all measures are carried out relative to the reference point (upper incisor). The average values (AV) with standard deviation (SD) are calculated, the values are given in centimetre.
We noticed that the LC rises by 0.872 cm relative to the rest position during the production of the pharyngeal / ʕ/ in different contexts. The average value of the HB elevation is 0.724 cm relative to the rest position. The constriction location is at 13.758 cm. The constriction opening is 1.157 cm. Thus, the production of the voiced pharyngeal consonant / ʕ/ involves a considerable elevation of both the larynx center (0.872 cm) and the hyoid bone (0.724 cm) relative to the rest position. The obtained value of the larynx center elevation is close to that given in (Ghazeli, 1977) and Alwan (1986) (about 0.9 cm and 0.7 cm). For the voiceless pharyngeal /ħ/, the average value of the LC raising is 1.644 cm, and the SD is equal to 0.383. The elevation of the LC during the production of the voiceless pharyngeal /ħ/ is 0.772 cm more than that of the voiced / ʕ/. Thus the elevation of the LC is more important during the production of the voiceless /ħ/ compared to the obtained value for the production of the voiced / ʕ/. The average value of HB raising is 0.597 cm and the SD is equal to 0.283. The constriction location is at 13.408 cm, and the constriction opening

Vowels in the studied contexts	HB raising	LC raising
/a/ in /ħ/ neighboring	0.458	1.197
/a/ in /ʕ/ neighboring	0.894	0.835
/a/ in plain coronal	0.290	0.361
/i/ in /ħ/ neighboring	0.447	1.184
/i/ in /ʕ/ neighboring	0.141	0.667
/i/ in plain coronal	0.429	0.404
/u/ in /ʕ/ neighboring	1.159	1.152
/u/ in plain coronal	0.428	0.3

Table 2: The elevation of the hyoid bone and the larynx center during the production of the vowels /a, u, i/ in pharyngeal neighboring and in plain coronal contexts

is 1.078 cm, the obtained constriction opening is close to those given in (Sylak, 2013); the pharyngeal articulation was modeled with a length of constriction of 1.069 cm . From the obtained measurements, we stated that the Moroccan Arabic pharyngeal consonants are produced with a raised larynx and evenly a raised hyoid bone relative to the rest position and these results are in accordance with the results regarding the Tunisian Arabic and Iraqi Arabic and Kurdish (Al-Ani, 1970; Butcher, 1987; Zawaydeh, 1999; Ghazeli, 1977; Alwan, 1989; Al-Tamimi, 2009). In the second part of this section, we explore the articulatory effects of these consonants on adjacent vowels. First, the positions of LC and HB are measured during the production of the three vowels in plain coronal contexts (LCplc and HBplc), and then in pharyngeal contexts. During the production of the vowel /a/ (twenty two tokens of /a/ in plain coronal contexts), LCplc rises by 0.361 cm and the HBplc rises by 0.290 cm. For the vowel /u/ (twenty tokens of /u/ in plain coronal contexts in the corpus), the LCplc rises by 0.428cm and the HBplc rises by 0.3 cm. For the vowel /i/, the LCplc rises by 0.429 cm and the HBplc rises by 0.404 cm (for the thirteen tokens of /i/ adjacent to plain coronal contexts in the corpus). The elevation of the LC and HB during the production of the three vowels in plain coronal consonants neighboring does not exceed 0.429 cm relative to the rest position. In the other hand, in pharyngeal neighboring, we noticed that the elevation of the LC and the HB is more important as shown by the measurements given in Table 2.

For the vowel /a/ in / ʕ/ neighboring, the LC rises by 0.835 cm relative to the rest position, it rises more compared to LCplc (0.361 cm). The HB rises by 0.894 cm, it rises also more compared to HBplc (0.290 cm). In /ħ/ neighboring, the LC rises by 1.197 cm, it rises 0.82 cm more compared to LCplc. The HB rises by 0.458 cm more than HBplc. We noticed that LC and HB rise more in the voiceless /ħ/ neighboring compared to the voiced /ʕ/. For the vowel /i/, in /ħ/ neighboring, the LC rises by 1.184 cm relative to the rest position, it rises 0.76 cm more compared to LCplc. The HB rises by 0.447 cm, it is in the same range of displacement as in plain coronal contexts. In /ʕ/ neighboring, the LC rises by 0.667 cm, it rises by 0.24 cm more compared to LCplc. The HB rises by 0.141 cm (close to the rest position). From these measurements, we noticed that the elevation of the LC during the production of /i/ in the voiceless /ħ/ neighbouring is more important compared to the obtained LC in the context of the voiced /ʕ/. For the vowel /u/ in /ʕ/ neighboring, the LC rises by 1.152 cm relative to the rest position, it rises by 0.72 cm more compared to LCplc. The HB rises by 1.159 cm (0.86 cm more than HBplc). We conclude that the larynx vertical movement and the hyoid bone gestures for pharyngeal consonants in Moroccan Arabic overlaps as coarticulation on adjacent vowels; it exhibits a coarticulatory spread to adjacent vowel, and that consonants do not exert the same influence on adjacent vowels as shown by the obtained measurements. As mentioned earlier, the acoustic output varies according to the behavior of the active gestures and the obtained results from the articulatory study lead to additional questions about the acoustic consequences of change in the vertical movement of the larynx on vowels adjacent to pharyngeal consonants. Hence, an acoustic study of the vowel quality was conducted in order to determine the extent to which vowels could be affected by that environment. The software Praat is used for the segmentation of the words into phonemes and for the measurement of the formants values.

3.1 Acoustic Results

This part of the study will observe how vowel quality is affected by a pharyngeal consonants neighboring in Moroccan Arabic language. The Coarticulatory effects will be evaluated through the frequency modifications of the formants F1, F2, F3, F4 and the variation in the distance between the two first formants F2-F1. The Table 3 summarizes the formants values of the three short vowels /a, u, i/ in the studied contexts.

The formants values of the vowel /a/ in plain coronal contexts are: the AV of F1 is 519.60 Hz with SD equal to 46.46, F2 is 1 573.437 Hz with SD =94.37, F3 is equal to 2 485.809 Hz, with SD equal to 137.43, the AV of F4 is 3 676.291 Hz with SD equal to 95.33. In /ħ/ neighboring, we noticed that the value of the first formant F1 increases by 223.76 Hz, F2 undergoes a moderate increase of 24.62 Hz, F3 decreases by -11.65 Hz and F4 increases by 148.54 Hz. In /ʕ/ neighboring, F1 increases by 134.79 Hz, F2 increases by 132.78 Hz, F3 undergoes a moderate increase of 53.87 Hz, and F4 increases by 91.89 Hz. The effect of the voiceless /ħ/ on F1 and F4 is more important than that of the voiced /ʕ/, F2 is more influenced by the voiced /ʕ/, F3 is less influenced by the pharyngeal contexts. We measure the coarticulatory effects that the studied pharyngeal consonants exert on adjacent vowel /a/, thus the distance between F2-F1 shows a significant decrease around 800 Hz compared to plain coronal contexts (1 000 Hz), the mean difference of F2-F1 in pharyngeal contexts and F2-F1 in plain coronal consonant contexts is 200 Hz, it reflects a considerable coarticulatory effect in /ħ/ context and weak in plain coronal contexts. The mean difference of F2-F1 in /ʕ/ contexts and F2-F1 in plain coronal contexts is 2.003 Hz, it reflects a coarticulatory effect which is exerted in a similar way in the two contexts. The voiceless pharyngeal /ħ/ has a considerable effect on the adjacent vowel /a/, in the voiced /ʕ/ neighboring the difference is weak compared to that measured in /ħ/ contexts. Concerning the vowel /i/ in plain coronals contexts, the AV of F1 is 378.77 Hz with SD equal to 49.5, the AV of F2 is 1 881.35 Hz, with SD =128.08, F3 is equal to 2 729.54 Hz, and SD is equal to 188.23, the AV of F4 is 3 681.63 Hz, with SD = 84.33. In /ħ/ neighboring, F1 increases by 214.32 Hz, both F2 and F3 undergo a slight variation, F4 increases by around 72 Hz. The mean difference between F2-F1 in /ħ/ contexts and F2-F1 in plain coronal contexts is 214.06 Hz, the coarticulatory effect is strong in /ħ/ contexts. In /ʕ/ neighboring, F1 increases by 181.83 Hz, F2 increases by 90.35 Hz, the mean difference of F2-F1 in /ʕ/ contexts and F2-F1 in plain consonants contexts is 91.44 Hz, the coarticulatory effect is weak compared to that measured in /ħ/. F3 increases by 86.88 Hz, and F4 increases by 305.56 Hz. Thus, the voiceless pharyngeal /ħ/ has a strong coarticulatoty effect on the vowel /i/ as for the vowel /a/. As regards the vowel /u/ in plain coronal contexts, the AV of F1 is 464.41 Hz with SD = 48.66, F2 is equal to 1 184.15 Hz, and SD equal to 178.35, the AV of F3 is 2 542.37Hz, with SD equal to 156.04, the AV of F4 is 3 607.9, and SD =103.82. In /ʕ/ neighboring F1 increases by 239.81 Hz, F2 decreases by -64.86 Hz, the distance F2-F1 decreases in pharyngeal contexts (around 400 Hz) compared to plain coronal contexts (around 700 Hz), the mean difference of F2-F1 is 300 Hz. F3 increases by 88.95 Hz, and F4 increases by 127.49 Hz. For the three vowels, the first formant F1 increased significantly over 200 Hz in the pharyngeal environment; it reaches 223 Hz for /a/, 239 Hz for /u/ and 214 Hz for /i/. From these results, we reported that the vowel height represented by the first formant F1 influenced greatly by the adjacent pharyngeal consonants for /a/ and /i/. This result converges with those given in (Al-Ani, 1970; Butcher, 1987; Ghazeli, 1977; Bin-Muqbil, 2006; Zawaydeh, 1999). The larynx position rises from 0.6 cm to 1.19 cm in pharyngeal neighboring, the F1 increases up to 200 Hz (25% to 43% for /a/, 48% to 60 % for /i/, and around 50% for /u/) in these environments. We noticed a correlation between the elevation of the larynx and the degree of the coarticulatory effects.

4 Conclusions

This study presents results corresponding to the production of the MA vowels in the contexts where the larynx rises considerably, and the fact that the larynx rises decreases the length of the pharynx cavity, this involves a shortening (or a contracting) of the entire vocal tract which can explain well the obtained results. In contrast, when the larynx is lowered, the results will be opposite to that given above because the lowering of the larynx has the physical effect of lengthening the vocal tract and obviously the acoustic effects is expected to be opposite to those given in our study as reported throughout Marchal's study (2010) regarding the consequences of change in the vertical dimension of the pharynx due to the larynx lowering. In this study we focused on the larynx and the Hyoid bone raising which are the main active gestures during the production of the studied pharyngeal consonants, the obtained results show a correlation between the elevation of the larynx and the degree

vowels	F1(Hz)	F2(Hz)	F3(Hz)	F4(Hz)
/a/ in /ħ/	743.36 SD(21.2)	1598.06 SD(241.87)	2474.15 SD (181.6)	3824.83 SD(127.6)
/a/ in /ʕ/	654.39 SD(40.42)	1706.22 SD(159.46)	2539.67 SD(66.43)	3768.18 SD(89.16)
/a/ in pcc	519.60 SD (46.46)	11573.43 SD(94.37)	2485.80 SD(137.43)	3676.29 SD(95.33)
/u/ in /ʕ/	704.22	1119.64	2631.32	3735.39
/u/ in pcc	464.41 SD (48.66)	1 184.15 SD (178.35)	2542.37 SD (156.04)	3607.9 SD (103.82)
/i/ in / ħ/	593.09	1881.61	2708.745	3754.375
/i/ in /ʕ/	560.56	1971.70	2816.42	3 987.19
/i/ in pcc	378.77 SD (49.50)	1881.35 SD (128.08)	2729.54 SD (188.23)	3681.63 SD (84.33)

Table 3: Average values of the formants with SD for the three short vowels in pharyngeal and plain coronal contexts

of the coarticulatory effects. The studied pharyngeal consonants, by exerting a strong coarticulatory effect, are therefore distinguished mainly by a narrowing of the distance between the two first formants F2-F1. Thus, we can deduce that the increase in the values of F2-F1 reflects a decrease in the coarticulatory effect exerted by the consonant on adjacent vowel, and vice versa. When the difference (in Hz) between the two F2-F1 (plain coronal consonants – pharyngeal consonants) is high, it reflects totally opposite degrees of coarticulatory effect, strong in pharyngeal contexts and weak in plain consonants contexts. When the difference between F2-F1 (plain coronals) and F2-F1 (pharyngeal) tends towards zero or weak, it reflects a coarticulatory effect which is exerted in a similar way in the two contexts. The net result of laryngeal raising is to bring F1 close to F2 for the three studied vowels /a, i, u/.

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