File ID	57879
Filename	8 General discussion and conclusion

SOURCE (OR PART OF THE FOLLOWING SOURCE):

Type	Dissertation
Title	Aspects of Pharyngeal Coarticulation
Author	A. Elgendy
Faculty	Faculty of Humanities
Year	2001
Pages	312
ISBN	9076912106

FULL BIBLIOGRAPHIC DETAILS:
http://dare.uva.nl/record/90887

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General discussion and conclusion

Abstract

The main findings of the present study, which were presented in the previous chapters, are summarized and discussed in this final chapter. Some of the implications of the results obtained, as well as some of the limitations of the present study, are stated. A brief account on future work related to the main topic of the thesis is presented.

8.1. Introduction

The current study was intended to investigate pharyngeal articulation in normal speech as exemplified in Egyptian Arabic. For that purpose, we designed a series of experiments reported in chapters 2, 3, 4, 6, and 7. Using diversified methods, the study examined the movement patterns of various articulators and their acoustic consequences during the production of pharyngeal consonants. Numerous research questions were posited in Chapter 1, which we took as motivation to conduct the experiments included in this study. The most primary of these questions are: 1) Is the current definition of pharyngeal articulation precise enough? 2) What is the relationship between pharyngeal and nasal articulation?; what is the nature of coarticulation in the pharynx? And the most crucial question in our investigation: 3) Is the jaw actively involved in the production of consonants, particularly for pharyngeal consonants?

We also attempted to explain why pharyngeal consonants are rarely used in the sound inventories of the world languages. We also tried to provide answers to other questions such as why the jaw is open (a typical feature for vowels) during pharyngeal consonants as seen in published x-ray pictures (cf. Chapter 1)? Why do non-native speakers, when mimicking Arabic words, apparently have difficulty in producing intelligible pharyngeal consonants and why do native children take more time to acquire the production of pharyngeal consonants compared to oral consonants? What causes the pharyngeal and the laryngeal consonants to behave phonologically similar as one sound class?

All these questions required that we also study the dynamic aspect of pharyngeal consonant production. The answers that our present study offered to these questions are summarized and briefly discussed in the following sections.

8.2. Defining pharyngeal articulation in Arabic

In the present study diverse methods were unavoidably used to obtain empirical data on the use of the pharynx in speech production and to study the coarticulatory effects due to the presence of a pharyngeal consonant in a variety of phonetic contexts. Pharyngeal consonants have always been described as phonetically complex speech sounds, although no data verifying or explaining this claim can be found – to the best of our knowledge – in the literature. The present study, however, offers a thorough and illustrative explanation to that complexity. We stated in Chapter 2 that the intricacy of pharyngeal articulation is due to the involvement of coordinated activities of several articulators. We found several articulatory gestures to be occurring simultaneously during the production of pharyngeal consonants. The present study offered several interesting findings concerning the phonetics and phonology of pharyngeal consonants in Arabic.

Speech scientists and linguists dealing with articulatory modeling take for granted that the production of Arabic pharyngeal consonants is solely attained by retracting the tongue root into the pharyngeal cavity. This phonetic description seemed to be inadequate to explain the claimed complexity as well as the observations we collected (see discussion in Chapter 1) to motivate conducting the present investigation. We provided evidence, using the results of the experiments we reported in Chapters 2 and 3, to account for the origin of this complexity.

Moreover, the present study focused on the phenomena of coarticulation specifically to account for these motor activities involving the pharynx to produce speech sounds. In that respect, we view the pharynx as a peculiar structure in the sense that it is a non-rigid resonating cavity and not a typical movable articulator such as the lips, the tongue, the velum, the larynx or the jaw. It is expected that the coarticulation involving the pharynx would be different from, say, the lips with the jaw or the velum with the tongue. It is a fact, supported by our present findings, that the pharynx is mechanically connected to most of the movable articulators, used to produce speech. Therefore, we hypothesized earlier (cf. Chapter 1) that the nature of the coarticulatory process involving the pharynx as a place of articulation will require the coordination of the movement of several other articulators. This hypothesis was based on the anatomical certainty that the pharynx is linked to several other parts of the vocal tract more than the lips to the tongue or the jaw to the velum, for instance. One of the central tasks of speech research, on one hand, is to explain the process of coarticulation, i.e., the overlapping between articulatory gestures in space and time. On the other hand, modeling coarticulation requires definition of its temporal extent, i.e., carryover and anticipatory types of coarticulation. Therefore, we examined the timing relationship between these various articulators in order to determine how the pharynx is used to produce distinct speech sounds. The findings concerning this issue will be discussed in the following subsection.

8.2.1. Dynamic aspects of pharyngeal coarticulation

Several phonological observations indicated that there might be a connection between laryngeal, pharyngeal and nasal articulations. What type of relation could this be? Why is pharyngeal articulation used as a substitute to some oral consonants by cleft palate patients (suffering from hypernasality) whose native languages lack pharyngeal consonants, e.g., American English, Japanese and Swedish? (cf. Chapters 1 and 2).

In terms of the dynamic aspects of pharyngeal articulation, it appeared that the process of pharyngeal consonant production involves the interaction of several articulators (cf. Chapter 2). These articulators are the velum, the epiglottis, the larynx complex and the jaw, which were observed to be highly synchronous in their activities during the production of a pharyngeal consonant. Accordingly, we defined the true pharyngeal consonants as epiglottal pharyngeal approximants. The epiglottal component, manifested as a downward bending of the epiglottis, contains two subcomponents, i.e., a constricted glottis and a raised larynx. The pharyngeal component involves the active contraction of pharyngeal muscles (cf. Chapter 2 and Figures 5.3 and 5.4) which leads to a constricted lower pharynx at the level of the epiglottis. We consider the true pharyngeal consonants to be approximants rather than fricatives (as they are commonly described) because the degree of constriction is less than that for proper fricative consonants as aerodynamic data has shown (cf. Section 4.4.3.1). This phonetic definition, though concise, is adequate to explain why pharyngeal consonants are thought to be intricate phonemes. That definition may furthermore explains why pharyngeal articulation is rarely used in the languages of the worlds. The speech of languages of the world tends to make use of simple sounds rather than of complex sounds (cf. Section 1.1).

In addition to the complexity of pharyngeal consonants, in terms of the number of articulators involved, the speaker needs to learn how to move the jaw simultaneously with the tongue in two opposite directions. One case is that of producing a pharyngeal consonant in an emphatic (pharyngealized) environment. The speaker needs also to learn how to lower the jaw to an extreme position (24 millimeters on average in initial position), which is a quite large degree of opening compared to oral consonants and even to low vowels (cf. Chapter 3).

The complex pharyngeal gestures require that the speaker first learns how to lower the jaw to that unusual (excessive) position without losing control over the utterance temporal pattern. Second, the speaker should learn how to manipulate the tongue muscles to form the particular shape (as an inverted V) while the jaw is maintained open. Third how to constrict and elevate the larynx as well as the hyoid bone. This mechanism is achieved by using the neurologically-based anatomical functional chain, explained in Section 2.4.1.5. The remaining gestures, a prerequisite for pharyngeal consonants, are active contraction of the pharyngeal constrictor muscles at the level of the epiglottis and contraction of the muscles connecting the epiglottis and arytenoids. These movements affect the length and tension of the vocal folds. Comparably, these activities are attained through using the same group of muscles as in the pharyngeal phase of normal swallowing. The resulting sound due to all these interactive and coordinated movements is a pharyngeal consonant (cf. Section 2.4.1).

Although any speaker knows how to manipulate this so called "functional chain" during the pharyngeal phase of swallowing, still s/he needs to learn how to open the jaw to an extreme position while the group of muscles involved in this *chain* are together in action. The jaw is completely closed during the pharyngeal phase of normal deglutition and the tongue presses against the hard palate (try dry swallowing for example). We speculated (in Chapter 6) that the untrained non-native speakers of Arabic encounter tremendous difficulty to produce correct pharyngeal consonants because they cannot switch to these complex articulatory gestures while keeping the jaw opened to a great degree. Also the bilingual native children take a considerable amount of time to learn these sounds because they need to learn first the same gesture for swallowing with an opened jaw. The group of muscles involved during the pharyngeal phase of swallowing, i.e., the functional chain, seems to be similar to that used during the production of lower pharyngeal consonants. We further speculate that the shape of the tongue assumed, as well as the state of the larynx complex including bending of the epiglottis during pharyngeals, are due to the action of this chain of muscles. Cleft palate patients from different language communities other than Arabic (cf. Section 2.4.6), use pharyngeal articulation as an alien substitute because it allows communication with a part of the nasal cavity and also creates a controllable constriction in the pharynx. The cleft palate speakers also exhibited a similar action of the larynx-epiglottis movements as well as showed similar tongue shape to that during normal pharyngeal articulation. These two articulatory gestures are used by these patients as a solution to avoid the leakage of the airflow through the nose due to the cleft in the roof of the mouth. However, EMG measurements are needed in order to obtain data to verify the above-mentioned assumptions.

We studied the dynamics of the pharyngeal structure during the production of consonants articulated in the back cavity of the vocal tract via fiberscopic video-imaging regestration. The results showed that the production of pharyngeal consonants is characterized by 1) an opened velopharyngeal port even in non-nasal context, 2) inward displacement of lateral and posterior pharyngeal wall, 3) active bending of the epiglottis, 4) simultaneous posterior-anterior tilting of the arytenoids accompanying the ascending of the larynx. The degree of velum elevation was found to be sensitive to the constriction location as well as to tongue height. In addition, the down folding of the epiglottis cartilage is synchronized with the sphincteral contraction of the pharyngeal wall (cf. Chapter 2). These findings contribute a good deal to account for several phonological and phonetic observations which we stated earlier in section 1.10. The interaction we found between the nasal and the pharyngeal cavities is mechanically grounded. That can be verified when considering the anatomical connection between various pharyngeal muscles that cause the velum to be pulled down, hence leading to an open velopharyngeal port.

8.2.1.1. The secondary role of the tongue during pharyngeal articulation

We argued in Chapter 2 against the view which considers the tongue as the main articulator used for creating the constriction in the lower pharynx during pharyngeal consonant production, as it is commonly believed. Our view regards the tongue as playing a secondary role in pharyngeal consonant production. This argument is supported by the fact that during pharyngeal consonants the tongue takes that peculiar shape instead of an assimilated shape to the following or preceding vowel. The reason, we claimed, is because the tongue undergoes mechanical constraints stemming from its connection to the hyoid bone and the mandible which both are connected to the larynx complex. We also have demonstrated (cf. Chapter 2), by measuring the degree of displacement (inward contraction) of the pharyngeal wall, that the pharynx is actively constricted during the production of pharyngeal consonants. It seems that the common denominator among all the available physiological data is that the tongue is assuming the pyramidal shape (inverted "V") and that the larynx and the hyoid bone are substantially raised upwards while the epiglottis is bend backward. Recall that a similar maneuver was reported to be used by Japanese cleft palate patients. This indicates that pharyngeal articulation is achieved by similar mechanism to that used during the pharyngeal phase of swallowing. With the jaw open, as during the lower pharyngeal consonants, the tongue assumes the inverted V shape, maybe aiming to get in contact with the roof of the mouth such as during the pharyngeal phase of swallowing.

Based on our data (Chapter 2), we inferred that the mechanism used to produce pharyngeal consonants is similar to that during the pharyngeal phase of normal swallowing. Hence, the vocal tract configuration associated with pharyngeal consonant production is considered to involve the tongue as a secondary articulator. Due to certain biomechanical constraints, the tongue assumes that shape which yields two secondary constricted points, one closer to the mid of the hard palate and the other at the level of the epiglottis (see Section 1.11). These two constriction locations are expected to have an effect on the acoustic parameters characterizing the speech signal associated with pharyngeal consonants. This shape, as we suggested in Chapter 2, is a characteristic articulatory gesture for pharyngeal consonants. The tongue was observed to be additionally drawn backward during pharyngeal consonants in a pharyngealized environment (cf. Section 5.4). This observation can be taken as an added evidence to support our claim that the major constriction associated with the pharyngeal consonant is achieved by contraction of the pharyngeal wall and not by tongue root retraction. The tongue would not retract more for an "emphatic pharyngeal" if the retraction of the tongue root is an inherent feature of the true pharyngeal consonants.

8.2.1.2. The secondary role of the pharynx during emphatic consonants

We also have demonstrated that the mechanism underlying the production of true pharyngeal consonants in Arabic is different from that used to produce pharyngealized consonants (cf. Chapter 2). Several previous studies showed that the tongue is the main articulator during pharyngealized consonants. However, the tongue is stiff and arches upwards during the production of true pharyngeal consonants, indicating its secondary role in narrowing the pharynx. The emphatic (pharyngealized) coronal consonants /sˤ, zˤ, tˤ, dˤ/ are distinguished from the true pharyngeal consonants /ʕ/ and /ħ/ by a lowered tongue dorsum. They share retraction of the tongue root at the level of the epiglottis which is deliberate only in the case of emphatic consonants. As for the epiglottis, we found that during the true pharyngeals it comes very close to the posterior wall of the pharynx and that it bends downward thus covering the top of the arytenoids. These activities are accompanied with a constriction in the glottis itself (cf. Chapter 2). Nevertheless, we argue that neither velum lowering nor laryngeal constriction is a characteristic of pharyngealized consonants in Arabic.

Regarding the manner of articulation of the true pharyngeal consonants, our results suggest that the makeup of the constriction we found in the lower pharynx is not adequate to produce enough friction to consider these sounds as fricatives, hence they are considered as approximants. However, to establish a more precise definition, further investigation is needed, e.g., EMG combined with X-ray motion picture or MRI. The pharyngealized consonants /sˤ, zˤ/ are to be considered as fricative sibilants The impact of the secondary pharyngeal feature induced by retracting the root of the tongue does not change its acoustic clues, rather it effects only the spectral properties of the surrounding vowels.

8.3. Acoustic affiliations of pharyngeal articulation dynamics

In Chapter 4, we investigated some of the acoustic properties of the pharyngeal consonants in Arabic words recorded from some 9 native speakers. The results showed that it is possible to relate, to a certain extent, the articulatory dynamics characterizing pharyngeal consonants to the spectral clues attributed to their acoustic signal. The significant damping of F1-amplitude and the increase of its bandwidth measured at the midpoint of the voiced pharyngeal consonant as well as the following vowel, pointed to the nasal coupling observed during its production. The difference between the values of first and second formant frequencies for the voiced pharyngeal consonant and the following vowel can indicate the constriction location of the consonant in the back cavity.

We found the fundamental frequency of the voiced pharyngeals to be markedly low, which can be ascribed to the constriction of the glottis. Moreover, the weak energy found in the high region of the spectrum of the pharyngeal consonant can be attributed to the active bending of the epiglottis towards the arytenoids. In addition, mandibular adjustments were reflected as a compensatory effect on the duration of the vowel adjacent to the pharyngeal consonant. We found that all the values of these acoustic parameters can be defined in order to be incorporated in any articulatory model such as that described in Chapter 5. These findings are also taken as supportive evidence to validate our main hypothesis that the production of pharyngeal consonants involves several articulators and as a verification of the complexity of pharyngeal consonants. However, further extensive investigation of the acoustics and perception of pharyngeal articulation with more subjects including female speakers is needed before a comprehensive account can be given about this issue.

8.4. Jaw contribution to pharyngeal consonant production

The results obtained from the jaw kinematics experiment with 6 native speakers reported in Chapter 3 on the jaw movement provide additional support to the interpretation we offered about the consequence of the mechanical perturbation on the structure of Arabic language. We concluded that the resulting coarticulatory effect, due to the compounded articulatory pharyngeal gestures, causes the jaw to sustain certain mechanical constraints. These constraints are realized as antagonism of the jaw movement to the tongue movement and temporal reorganization of the syllable containing pharyngeal consonant. That is, the synergies involved in controlling the production of pharyngeal consonants restrict the jaw and the tongue from anticipating the articulation of the upcoming phonemes until the motor command for issuing the pharyngeal consonant is completely executed. This articulatory maneuver causes restrictions on the distribution of pharyngeal consonants to diffuse over the arrangement patterns of the rest of the consonants.

We also suggested that the classification of Arabic consonant inventory into categories can be made according to the degree of inherent jaw height associated with each individual consonant. Thus, Arabic consonants can be classified into high, central and low, in terms of their degree of jaw height. This suggestion was supported by our results on the co-occurrence restrictions in Egyptian Arabic. There exists a hierarchical classification which starts from extreme low position for the pharyngeal consonants and ends with the highest position for the sibilant consonants. The type of co-occurrence restrictions we observed showed that consonants in Arabic do fall into categories according to their degree of jaw height, i.e., degree of opening, exactly as do vowels in the traditional classification system. These results indicate that the path the jaw, and hence the tongue, takes to move from one location for a consonant to another within the utterance, will determine the overall duration of the utterance. Since we found Arabic consonants to be arranged in a sequence based on that relation, we take this piece of evidence to suggest that the timing control of a speech utterance is taken into consideration in the high level planning scheme (centrally in the brain) prior to actual speech is produced.

8.5. Modeling pharyngeal articulation

In Chapter 5, we presented a hypothetical model that describes the cognitive and motor processing of any given Arabic utterance containing a pharyngeal consonant. The model design was based on our findings regarding the dynamics of the back cavity and the jaw movements. Moreover, acoustic and articulatory parameters were described and presented as components that can be used in constructing a dynamic model for pharyngeal articulation.

In the global model (see Figure 5.1), we proposed two main strategies inferred from the particular curves characterizing the trajectories which the jaw passes through during pharyngeal articulation. These strategies were derived from the results obtained from the experiments reported in Chapters 2 and 3 on the dynamics of the back cavity as well as the jaw. The first strategy (a default) allows anticipatory coarticulation to take place in utterances that do not contain a pharyngeal consonant. The second strategy is used to handle the temporal perturbation that occurs due to the presence of a pharyngeal consonant. This perturbation was found to prevent the jaw anticipation for the upcoming phoneme before the gesture of the pharyngeal consonant is terminated. As a result, consonants in the same string are selected in terms of their inherent degree of jaw height in order to compensate for the temporal perturbation that occurs. This indicates that the speaker does not have to slow down or to speed up the movement of the articulator to compensate for the delay due to the perturbation effect caused by pharyngeal consonants. The choice of a compatible consonant in terms of inherent jaw height, as our results in Chapter 7 showed, supports our hypothesis that the timing is issued centrally. The path the jaw has to go through is adequately realized in the high level articulatory plan. This bears additional counter evidence against the existence of the so-called "proportional timing" during speech (cf. Chapter 3).

Our model predicts that consonants in a sequence are compatible in terms of their jaw height in order to maintain a unitary length of the morpheme which may be a characteristic feature of Arabic words. Results obtained from the experiments reported in Chapter 3 showed that vowels are found to accommodate the mandible position assigned to the pharyngeal consonant. Furthermore, the degree of jaw lowering is greater, i.e., more open, for mono-syllabic than for bi- or tri-syllabic words. All these results were verified and supported by the study we conducted in Chapter 7 which investigated the phonotactics patterns of the consonant inventory in Egyptian Arabic of the three main types, i.e., CVVC, CVCVC, CVCC. We took these findings to suggest that the jaw is involved in regulating the timing demands to organize the temporal aspects of syllables. We suggested that the timing pattern is *preplanned* because the Arabic language considers an inherent jaw height for each consonant while arranging the phonemes in a sequence to constitute a morpheme (cf. Chapter 7). During the execution of an utterance, the degree of jaw opening for each consonant, which is determined prior to the listing of timing instructions, will be subjected to modification according to the demand of the temporal pattern (syllable structure, stress position, etc.), and according to the presence or the absence of a pharyngeal consonant in the utterance and its position in the word (cf. Chapter 3).

The syllable, as we have demonstrated in the present investigation, is affected by the open and closing phase of the jaw in the sense that consonants as well as vowels are not specified to either open or closed jaw but rather to the temporal specifications of the syllable. That is, in our opinion, the jaw cycle in the open phase will require a subsequent closing phase in order to enhance the contrastive perceptual saliency, thus affecting the overall duration of the syllable. Unlike other views, e.g., Lindblom (1983) and Keating et al. (1989), we suppose that the interrelationship between vowel jaw height and consonant jaw height is determined by the timing organization of the syllable's constituents. Both vowels and consonants are subjected to a shortening or lengthening effect depending on the degree of flexibility of the phoneme in terms of its acoustic length. In that respect, vowels are considered to be more flexible phonetic segments than consonants so they can undergo a greater degree of lengthening/shortening effects. Our results strongly suggest that the opened jaw is not necessarily a characterizing feature of vowels only, but also of pharyngeal consonants. However, further investigation is needed in order to make these assumptions eligible.

Our results on the acquisition of pharyngeal articulation also support this idea (cf. Chapter 6). These results revealed that the acquisition of pharyngeal consonants by 10 bilingual children has a gradual emergence which is correlated with the relative degree of inherent jaw height associated with each consonant. That is, within the same phonetic class of speech sounds, the consonant which has a greater inherent jaw opening was acquired later than the consonant which has a lesser degree of jaw opening. The 6 non-native adults on the other hand, showed a tendency to substitute lower pharyngeal consonants by sounds with less degree of jaw opening within the same phonetic class. This suggests that the biomechanical constraints which induce complexity characterizing the articulation of pharyngeal consonants have a considerable impact on the process of acquisition, another aspect which our hypothetical model also could predict.

8.6. Co-occurrence restrictions affecting pharyngeal consonants

We have shown that pharyngeal consonants are distinguished by being subjected to severe bio-mechanical constraints which cause a considerable amount of temporal perturbation on the speech utterance (cf. Chapters 2 and 3). In order to adapt to these perturbations the speaker uses a secondary strategy to control inter-consonantal timing (cf. Chapter 4). In Chapter 7 we have demonstrated that the co-occurrence restrictions governing the Arabic phonotactic rules are based on a hierarchical ranking order depending on the inherent degree of consonant's jaw height. Accordingly, we classified the consonants in Arabic into three distinct categories, i.e., high, central and low.

We further suggested that the mandible accommodates the position of the pharyngeal consonant in order to preserve the temporal pattern organizing word structure. This assumption was motivated by the observation presented in Chapter 3 concerning the jaw trajectory of the vowel in the vicinity of a pharyngeal consonant. We found that the vowel adapts the jaw position assigned to the pharyngeal consonant in medial position and not in initial or final position. That the jaw accommodates the pharyngeal consonant position, and not the vowel position, suggests that the temporal pattern governing the syllable(s) is controlled by the jaw. The way this requirement is fulfilled depends significantly on the choice of compatible consonants in the vicinity of a pharyngeal consonant in terms of jaw opening associated with the consonantal composite. The duration of the vowel adjacent to the pharyngeal consonant has a compensatory interrelationship with other phonemes in the word as a function of the overall distance the jaw has to travel between various levels along the utterance. The target is to preserve certain temporal pattern among syllables. Recall that the frequency of occurrences of pharyngeal consonants in Arabic is high, although they are rarely used in the languages of the world.

We found that the jaw opening for pharyngeal consonants is greater than for low back vowels. This evidence supports our hypothesis stated earlier in Chapter 3 that the extreme jaw lowering associated with pharyngeal consonant production is a result of biomechanical constraints and should not be seen as a coarticulatory effect induced on the consonant from the preceding or following low vowel. Our results also show that pharyngeal consonants have lower jaw position even in the vicinity of high vowels, i.e., /i/, /u/. If this extreme degree of jaw displacement for pharyngeal consonants is taken as a result of the effect of the vowel height on the consonant height, why then was the jaw still found to be lowered during /ʕ/ and /ħ/ even in the vicinity of the high vowel /u/ (cf. Figure 3.5)?

8.7. General conclusion

The present study offers a more precise definition of pharyngeal articulation in general and sheds some light on the nature of coarticulation in the pharynx. It also offers an innovated phonetic classification of Arabic consonants. We classified Arabic consonants in terms of their inherent degree of jaw height, relative to the clench position, as low, central, and high. Jaw movements as an articulatory parameter are not actively integrated in the framework of current articulatory models of speech (e.g., task dynamics model). Our results suggest that the efficiency of these models can possibly be improved once the jaw activities are linked in their score of articulatory gestures. The results further suggest that any model seeking a universal framework of presentation should consider the jaw as an articulator that handles temporal specifications of syllable structure. One important implication attributable to the present study is that physiological constraints affecting the biomechanical system governing the vocal apparatus are centrally taken into account while planning the articulatory process.

8.8. Future research

The present study suffers from certain limitations regarding the scope of the investigated topics dealing with pharyngeal articulation. Perceptual evaluation of the acoustic clues of the speech signal associated with the production of pharyngeal consonants is one aspect which should be taken into consideration as future research work.

Moreover, in the present study only male voices were used, therefore, more experiments are needed in order to test female voices for comparison. Our present findings indicated that the elevation of the larynx body, which in turn affects the length of the vocal tract and the state of the glottis, which determines the level of the fundamental frequency, are characteristic features of pharyngeal articulation. Replicating our pilot study of aerodynamics of pharyngeal articulation (cf. Chapter 4) with more subjects and a wider range of test material would be worthwhile. It is also useful to extend the investigation on pharyngeal articulation to involve other Arabic dialects and various speech styles.

A phonological analysis for back consonants, in particular pharyngeals in Arabic, is a prerequisite for the verification of the phonetic description of this class of consonants. Therefore, it is essential to conduct comprehensive phonological and morphophonemic analyses of pharyngeal consonants. Investigation of pharyngeal articulation beyond the word level can be an important topic for future work. It will also be necessary to examine other languages of the world which use pharyngeal articulation, aiming towards a universal account on the use of the pharynx in speech production.

In the present study, we offered various articulatory as well as acoustic components for the purpose of dynamic modeling of pharyngeal consonant production. Articulatory synthesis is one method which can be used to test articulatory models. Our findings concerning the physiological representation of the pharynx and the related articulators involved in the pharyngeal articulation were adequate to predict the muscles that contributed to produce pharyngeal consonants. It can be useful, thus, to conduct an EMG study to examine the articulatory parameters in terms of the muscles involved in pharyngeal articulation. This is needed for synthesizing Arabic speech, particularly for utterances containing pharyngeal consonants. Our results obtained from the various experiments conducted in this project can be considered as an entrance to a wider filed of exploration of Arabic phonetics in general and pharyngeal phonetics in particular from a different perspective.