Aspects of Pharyngeal Coarticulation

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Pharyngeal articulation

Abstract
This chapter deals with the definition of pharyngeal articulation and the phenomenon of coarticulation particularly in Arabic. The literature on Arabic pharyngeal and pharyngealized consonants is reviewed and critically discussed. The statement of the problem concerning pharyngeal coarticulation is presented together with the main hypothesis which motivated the present study.
1.1. Introduction

1.1.1. The use of the pharynx in speech production

The vocal tract can be seen as a continuum where constrictions can take place at various locations during the encoding process of speech production. Conventionally, the vocal tract, when constricted at a given point, is divided into two compartments, i.e., front cavity and back cavity. In languages which make use of more inferior places of articulation than the level of the uvula, such as Arabic, the front cavity for uvular or velar sounds is mainly the area in the oral cavity from the lips to the soft palate. The back cavity, then, comprises the area from the level of the soft palate down to the surface of the laryngeal inlet, i.e., oro-pharyngeal and laryngeopharyngeal cavities. The back cavity is coupled to the nasal cavity via the velopharyngeal port. The division of the vocal tract into front and back cavities is based on acoustic manifestations. When the major constriction is located in the front cavity the first two formant frequencies in the spectrum are wide apart, e.g., as in high front vowels. These formants are closer together when the major constriction occurs in the back cavity, e.g., low back vowels (Klatt and Stevens, 1968). Figure 1.1 shows the shape of the vocal tract showing the three divisions of the pharyngeal cavity, i.e., the nasopharynx, the oropharynx and the laryngeopharynx and their relation to the oral cavity. In natural speech communication, the use of the pharynx as a primary place of articulation seems to be rarely involved in the production of phonemically distinct speech sounds as consonants. In a survey made on 317 of the world languages, it was found that there are relatively few languages which include pharyngeal consonants in their speech sound inventory (cf. UPSID, Maddieson, 1984).

For example, the sounds [ʕ] and [h] which are phonetically described as voiced and voiceless pharyngeal fricatives occur in only 2.5 % and 4 %, respectively, among all languages listed. Figure 1.2 shows data extracted from the UPSID phonetic database for selected consonants, indicating the number of the languages which use them. It can be seen that the number of languages using pharyngeal consonants in their inventory is far less than the number of languages using consonants articulated in the oral cavity. There are only eight languages containing the lower pharyngeal [ʕ] in this database, i.e., Arabic, Ewe, Iraqui, Kabardian, Kurdish, Shilha, Somali and Tigre. There are 13 languages containing the voiceless counterpart [h] and 54 languages containing one or more of the upper pharyngeals, i.e., the uvular [q, ʔ] or [k] in their speech sound inventory. Throughout this book the slashes / /, conventionally used to demarcate phonemes, are interchangeably used to denote the same as the square brackets [ ] which are used to demarcate allophonic realizations. It is beyond the scope of this study to account for the variations of the phonemes due to contextual differences. The class of pharyngeal speech sounds is particularly frequent in Semitic languages such as Arabic (Al-Ani, 1970; Delattre, 1971; Ladefoged, 1975; Ghazeli, 1977; May, 1979; Adamson, 1981; Elgendy, 1982) and Hebrew (Lauffer and Condax, 1972). These sounds may also occur in language families unrelated to Arabic, e.g., Caucasian (see Catford, 1983).

“Pharyngeal” in usual phonetic terminology defines a region or a space in the vocal tract; any gesture that impacts on that space can be said to have a pharyngeal component.
Figure 1.1. The shape of the vocal tract showing the three divisions of the pharyngeal cavity, i.e., the nasopharynx, the oropharynx and the laryngeopharynx.

Figure 1.2. Some selected consonants representing various places of articulation in the vocal tract and the number of languages which include them according to a speech sound inventory (data extracted from the UPSID Phonetic Database which included 317 languages of the world, Maddieson, 1984).
Pharyngeal articulation, whether used to produce consonants or vowels, is mainly ascribed to either a reduction or expansion, to various degrees, in the pharyngeal cavity size. The reduction in the pharyngeal cavity size can be achieved by an active manipulation of pharyngeal muscles. If an articulator such as the tongue moves backward or forward in the vocal tract, its movement will certainly affect the size of the pharynx. When the tongue body is retracted, causing reduction in the pharynx size, the pharyngeal cavity size is passively reduced since the pharyngeal muscles do not receive any neuromotor commands. The size of the pharyngeal cavity can also be altered by movements of the velum or the larynx. The degree of expansion or reduction depends on the direction of the movements of these two articulators. If the velum is lowered, the length, and hence the volume, of the nasal portion of the pharynx will be added to the rest of the pharyngeal cavity. Raising the larynx upward will diminish the length and size of the pharynx.

1.1.2. Primary versus secondary pharyngeal articulation
In terms of phonetic classification notations, articulators can be involved in the production of a sound in a variety of ways. When a major constriction is created by a given articulator, the articulation is called primary. The articulation is secondary when a major constriction is combined with another minor constriction. For example, a primary velar place of constriction can be combined with a secondary labial constriction (lip rounding) to produce a labialized velar sound. Accordingly, there are two major types of articulation in which the pharynx can be involved, a primary and a secondary pharyngeal articulation. A primary pharyngeal place of articulation, on one hand, exhibits a size reduction in the pharyngeal cavity with a major constriction located in the pharynx. This type of pharyngeal articulation can be achieved either actively or passively. The passive pharyngeal articulation can be achieved by movements of articulators such as the root of the tongue when occupying part of the pharynx. The place of constriction in the pharynx is considered as being primary as long as no other parts of the tongue body are involved in a narrower constriction during the same moment. This type of articulation is said to be a passive pharyngeal cavity size reduction because it is only the tongue, not the pharynx, which is involved in the neuromotor process. If the reduction is achieved by issuing neural commands directed to the pharyngeal muscles, thus leading to a reduction in the cavity size by muscle contraction, the pharynx will be actively involved in the articulation process. Accordingly, the speech planning is different and that will have implications on our understanding of the general theory of speech production.

The other type of articulation which involves the pharynx is called “pharyngealization” which is also known as “emphasis” in the phonetic literature. Pharyngealization is considered a secondary articulation because it is an added constriction to a primary place of articulation in another location in the vocal tract. Consider, for instance, a ‘phonetic segment’ which has a major constriction in the oral cavity, e.g., the apico-alveolar constriction of /d/. If the tongue is retracted and depressed, a reduction in the pharyngeal cavity size and an increase in the oral cavity size will occur. This reduction will add a secondary place of constriction to the major place in the oral cavity. Pharyngealization can be attributable to either a vowel or a consonant segment and it is in this case a secondary feature of articulation. A secondary articulation implies, by definition, the co-occurrence of a primary constriction together with the secondary constriction. The secondary constriction has always a lesser degree of stricture in the vocal tract.

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1 The term phonetic segment is used here in the sense of denoting a specific articulatory event which has a beginning and an end of a time interval assigned to a phoneme. It has no phonological value such as a bundle of features specified to a given phoneme, for instance.
TRACT than that of the primary stricture and is usually created by articulators which are not involved for the primary articulation is taking place (cf. Ladefoged, 1971, pp. 59). For instance, when a consonant such as the velar stop /k/ bears a secondary articulation, say, a labial stricture, the consonant will be phonetically described as a labialized velar and it is transcribed as /kʷ/. In this case the degree of constriction created by the back of the tongue and the velum at the velar area should be greater than that of labial approximation. The phoneme then is the combination of the velar and the labial articulatory gestures which occur almost simultaneously.

In the case of pharyngeal consonant production, the reduction in the pharyngeal cavity size is thought to be achieved by pulling the tongue root towards the posterior pharyngeal wall (e.g., Delattre, 1971; Ghazeli, 1977). The acoustic effect resulting from such a vocal tract configuration causes the first two resonance frequencies of the acoustic signal to approach each other. Accordingly, phonetic segments which are characterized by such a formant structure are defined as involving some degree of narrowing at a given point along the pharynx.

However, whether the reduction in the pharyngeal cavity size during the production of pharyngeal consonants is attained passively or actively is not a fully covered issue in the current phonetic literature. It is taken for granted, nowadays, that pharyngeal articulation, either primary or secondary, is achieved by bringing the tongue root closer to the posterior pharyngeal wall. That is, the major articulator responsible for creating the stricture in the pharynx, in both types of articulation, i.e., pharyngealization and true pharyngeal, is the tongue. It is within the framework of the present study to set up a more precise definition of speech sound categories involving the pharynx in their production.

1.1.2.1. Pharyngeal articulation in Arabic

Arabic, together with Amharic, Aramaic, Hebrew, and Tigrinya comprise the Semitic language family. The speech sound inventory of each of these languages contains consonants articulated in the pharynx or involving the pharynx in their production (cf. Maddieson, 1984). The Arabic language received a great deal of attention by the medieval Arabic grammarians since the beginning of the fourth Islamic century. One of the pioneering works which presented an extensive description of different levels of Arabic grammar, is ascribed to Sibawayh, a prominent linguist of the school of Basra. In his popular book “Al-Kitaab” (750 AD) a thorough description of the phonological system of Arabic was presented. Sibawayh is the first to provide a full account on the phonetic classification of the speech sound inventory of Arabic in general and on the pharyngeal and pharyngealized articulation in particular. His classification was based on the place of articulation of each consonant relative to the throat and the oral cavity. The classification also includes definitions of the manner of articulation for consonants, as well as laryngeal activity in terms of presence or absence of voicing. He has classified the speech sound inventory of Arabic (of his time) as having two main categories, i.e., the sounds of the throat and those of the mouth. The set of throat sounds are those consonants which are articulated in the back cavity while the rest of the inventory are those sounds articulated at various points between the soft palate and the lips. The term “Gutturals” is used in modern linguistics, often among phonologists, to describe the pharyngeal, laryngeal and uvular consonants of Arabic (cf., e. g., Harrell, 1975; McCarthy, 1991).

Sibawayh had defined three pairs of back consonants in terms of their place of articulation in the throat. The pair /ʔ, h/ have their place of articulation farthest down in the throat. As for the pair /ʕ, h/ their place of articulation is in the middle of the throat and finally /q, ɣ, x/ have their place located highest in the throat. In addition, his classification also made a distinction
between voiced and unvoiced (voiceless) sounds among pairs of consonants in Arabic. The terms “mahmos” (hamas = to whisper) and “maghor” (gahar = to speak loudly), indicate voiceless and voiced, respectively. Thus, for instance, the sounds /ʃ, k, ɣ/ were classified as voiced and /h, χ, q/ as voiceless sounds of the throat.

In addition to the true pharyngeals, Sibawayh recognized that the set of the plain oral consonants /t, d, s, z/ have counterpart pairs, which involve, in addition to their primary place of articulation in the oral cavity, superimposed constriction in the pharynx. He differentiated the sounds of the throat, i.e., pharyngeal and laryngeal consonants, from the pharyngealized consonants. He gave the term “the covered sounds” to the pharyngealized consonants since, he postulated, the contour of the tongue blade is covering (parallel or closer to) the surface of the soft palate (being retracted) during their production. The comparison was made according to the shape of the tongue during the plain set of oral dental consonants and that during the sounds of the throat (i.e., pharyngeals). Sibawayh’s definition, though not clear enough when using more than 1000 years old semantic terms, still points out that pharyngealized consonants involve only the tongue in their production and that the pharyngeal constriction associated with these consonants is attained by retracting the back of the tongue in the throat.

It should be noted that Sibawayh’s classical study of Arabic speech sounds influenced the methods of describing Arabic language in modern phonetic research. Several linguists who have started reviewing old Arabic literature in the beginning of the nineteenth century made use of Sibawayh’s studies (e.g., de Sacy, 1810; Wallin, 1855; Brücke, 1860; Haupt, 1890; Sievers, 1901; Schaade, 1911; Meinhof, 1921; Calzia, 1924; Marçais, 1948; Jakobson, 1957) (for a comprehensive review on the literature of emphatic sounds in Arabic see Giannini and Pettorino, 1982). However, the approaches they used were mainly dependent on impressionistic analyses based on auditory perception, especially to the unfamiliar Arabic sounds such as pharyngeal and pharyngealized consonants. Nevertheless, little attention was given to the fact that the Arabic language had passed through substantial historical developments leading to a wider range of variations among different dialects of Arabic language communities.

In the beginning of the nineteenth century several studies have been conducted by western scholars which included a description of Arabic pharyngeal sounds. The term “mofaxxama” which means “emphatic” was first introduced by de Sacy (1810) and it continued to be used up till now by modern linguists (e.g., Jakobson, 1957). This term refers to a class of speech sounds, namely, the set of dental consonants vis. /t, d, s, z/ which, in addition to their front cavity affiliation, display a concavity and depression of the tongue body and a retraction of the tongue dorsum toward the posterior wall of the pharynx (Ali and Daniloff, 1972). This articulatory maneuver results in what traditionally is referred to as the “emphatic consonants of Arabic”. The terms “pharyngealization” and “velarization” are sometimes used to refer to the same phenomena because of the similarities between the velum and the pharynx in terms of their acoustic effect, i.e., back cavity affiliation (cf. Nasr, 1959; Catford, 1977, p. 193).

To summarize, it appears from the historical background mentioned above that there are five true pharyngeal consonants in the phonetic systems of contemporary Arabic. Two consonants articulated in the lower pharynx, i.e., /f, h/ and three consonants articulated in the upper pharynx (oro-pharynx), i.e., /ʃ, χ, q/. From an acoustics point of view, pharyngeal consonants are all considered to be fricatives (cf. IPA’s consonants chart revised to 1993 and updated 1996 as shown in IPA handbook, 1999). However, in the Kiel convention of the International Phonetic Association meeting (1993), the description of the pharyngeal articulation was extended to include the voiced epiglottal fricative [ʕ], voiceless epiglottal fricative [H] and epiglottal plosive [ʔ]. As for the pharyngealized consonants, the symbol which denotes the voiced pharyngeal fricative [ʕ] was used as a diacritic mark replacing the
traditional subscript dot to be a superscript for the dental consonant when they are pharyngealized, e.g., [d̠] instead of [d]. Table 1.1 shows the set of the back consonants, i.e., the true pharyngeal consonants, the laryngeal consonants and emphatic (pharyngealized) consonants as classified in the sound system of Egyptian Arabic (Elgendy, 1982). The uvular consonants [x] and [χ] are realized as allophones of the velar consonants [γ] and [χ] in the emphatic environment, respectively.

1.2. Outlines of the structure of the Arabic language

Arabic is a peculiar language in terms of the way it is structured when compared to other unrelated language families such as Germanic. There is a huge bulk of knowledge accumulated on the western European languages which have had the merit of attracting the vast majority of study programs in modern phonetic research. Much less is generally known about Arabic, therefore, a brief description of the basics of the structure of Arabic is necessary and also will help to furnish a ground for the present study.

Table 1.1. The back consonants in Arabic. V. and V.L. stand for voiced and voiceless consonants respectively.

<table>
<thead>
<tr>
<th>Back Consonants</th>
<th>Laryngeal</th>
<th>Pharyngeal</th>
<th>Uvular</th>
<th>Velar</th>
<th>Pharyngealized</th>
</tr>
</thead>
<tbody>
<tr>
<td>V. V.L.</td>
<td>V. V.L.</td>
<td>V. V.L.</td>
<td>V. V.L.</td>
<td>V. V.L.</td>
<td>V. V.L.</td>
</tr>
<tr>
<td>?</td>
<td>h</td>
<td>?</td>
<td>k</td>
<td>γ x</td>
<td>d̠, z̠</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>t̠, s̠</td>
</tr>
</tbody>
</table>

Arabic word structure is based on a sequence of three or four consonantal elements embedded in a set of vocalic patterns by which derivational forms are generated. The stem is commonly referred to as the "root" of the word (Arabic: jazr) and it is denoted by the mathematical symbol √. The inflectional constructions, on the other hand, are paradigmatically obtained by adding prefixes, infixes or suffixes to the derived forms. There are 70 theoretically possible combinations which can be yielded from the affixation process. A combination of a root and a vowel pattern is called a “theme”. The stem common to a set of inflected forms may appear in several themes. Thus /katab-/ /katteb-/ and /-kteb/ are all themes of the stem of the verb root /k t b/ . Adding the feminine pronoun morpheme (–ti), for instance, will generate /katabti/ "you (feminine) wrote"; /kattebti/ "you (feminine) caused to write" and /tikteb/ "she is writing". For a more detailed account on Colloquial Egyptian Arabic (henceforth CEA) morphology see Aboul-Fetouh (1969). The morphological rules governing the word in Arabic are highly systematic. The three types of affixation, i.e., suffix, infix and prefix are used to generate different themes. Consider the example of the word morpheme /k t b/ “to write” in Table 1.2.

The syntax of an Arabic sentence is strongly linked to the phonological manifestation of the phonetic system. The final vowel in a word denotes which part of speech it is, i.e., whether it is a subject, an object or an adverb (see example in Table 1.3). The semantic unit is embedded in the elements of the root itself. The serial order of the consonants presented in the morpheme determines the basic meaning, i.e., the sememe. For instance /vr-k-b, v̄k-b-r, v̄b-r-k/, are roots in Arabic which have the basic meaning, to ride, to grow and to put down,
respectively. The derivational and inflectional forms generated due to the insertion of specific vocalic patterns are consistent in all of the words with only a few exceptions.

**Table 1.2.** The three types of affixation in Arabic, i.e., suffix, infix, and prefix used to generate different themes. (C) denotes any consonant; (Ø) denotes no vowel inserted in that position (an empty slot); (.) denotes syllable boundary; and (-) denotes the place where a consonantal element can be inserted while (−) denotes the place where a vowel can be inserted.

<table>
<thead>
<tr>
<th>Root $C_1C_2C_3$</th>
<th>Vocalic Pattern</th>
<th>Word-morpheme</th>
<th>English Gloss</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sqrt{k-t-b}$</td>
<td>-ae-ae-</td>
<td>kaetæb</td>
<td>to write</td>
</tr>
<tr>
<td></td>
<td>-o-i-</td>
<td>ko.tib</td>
<td>was written</td>
</tr>
<tr>
<td></td>
<td>-o-o-</td>
<td>ko.tob</td>
<td>books</td>
</tr>
<tr>
<td></td>
<td>-ææ-i-</td>
<td>kæætib</td>
<td>writer</td>
</tr>
<tr>
<td></td>
<td>-ææææ-</td>
<td>kææææb</td>
<td>he corresponded</td>
</tr>
<tr>
<td></td>
<td>-ææææ-</td>
<td>kææææb</td>
<td>a book</td>
</tr>
<tr>
<td></td>
<td>-ææææ-</td>
<td>kææææb</td>
<td>to cause to write</td>
</tr>
<tr>
<td></td>
<td>-ææææ-</td>
<td>kææææb</td>
<td>to register</td>
</tr>
<tr>
<td></td>
<td>-ææææ-</td>
<td>kææææb</td>
<td>was registered</td>
</tr>
<tr>
<td></td>
<td>-ææææ-</td>
<td>kææææb</td>
<td>desk</td>
</tr>
<tr>
<td></td>
<td>-ææææ-</td>
<td>kææææb</td>
<td>desks</td>
</tr>
<tr>
<td></td>
<td>-ææææ-</td>
<td>kææææb</td>
<td>libraries</td>
</tr>
<tr>
<td></td>
<td>-ææææ-</td>
<td>kææææb</td>
<td>documents</td>
</tr>
<tr>
<td></td>
<td>-ææææ-</td>
<td>kææææb</td>
<td>register objects</td>
</tr>
<tr>
<td></td>
<td>-ææææ-</td>
<td>kææææb</td>
<td>registers</td>
</tr>
</tbody>
</table>

**Table 1.3.** Final vowel indicator to the word’s part of speech in Arabic. The example shows the word kitææb “a book” denoted by the verb root $\sqrt{k-t-b}$ “to write”.

<table>
<thead>
<tr>
<th>Vocalic Pattern</th>
<th>Paradigm</th>
<th>Lexime</th>
</tr>
</thead>
<tbody>
<tr>
<td>i-ææ-on</td>
<td>kitææbon</td>
<td>subject (agent)</td>
</tr>
<tr>
<td>i-ææ-en</td>
<td>kitææban</td>
<td>object (antecedent)</td>
</tr>
<tr>
<td>i-ææ-in</td>
<td>kitææbin</td>
<td>adverb</td>
</tr>
</tbody>
</table>

1.3. Diglossia

The development that the Arabic language has undergone is manifested in the form of the contemporary Arabic version as it is known today, i.e., Literary Standard Arabic, compared to the classical version of the language. Several other dialectal variations have continued to co-exist with the standard version.
The considerable amount of the documented work done on Arabic linguistics in the old times enabled modern linguists to benefit from the massive data reported in several textbooks. The interaction between the classical Arabic and the modern contemporary varieties of the language is referred to as Diglossia (Ferguson, 1959; 1978). For speech technology applications, knowledge is needed about the differences found among the dialectal variants and about the characteristics of the unified contemporary standard Arabic.

Table 1.4. Consonant inventory in the sound system of Colloquial Egyptian Arabic. V and VL stand for voiced and voiceless consonant, respectively. The pharyngeal consonants are classified as fricatives according to the IPA consonant chart.

<table>
<thead>
<tr>
<th></th>
<th>Stop</th>
<th>Fricative</th>
<th>Nasal</th>
<th>Lateral</th>
<th>Trill</th>
<th>Glide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilabial</td>
<td>V</td>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labiodental</td>
<td>V</td>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dental</td>
<td>V</td>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alveolar</td>
<td>V</td>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palatal</td>
<td>V</td>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velar</td>
<td>V</td>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uvular</td>
<td>V</td>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pharyngeal</td>
<td>V</td>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glottal</td>
<td>V</td>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emphatic</td>
<td>V</td>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1.5. Short and long vowels in contemporary Egyptian Arabic.

<table>
<thead>
<tr>
<th></th>
<th>Short Vowel</th>
<th>Long Vowel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Front</td>
<td>Central</td>
</tr>
<tr>
<td>High</td>
<td>i</td>
<td>ii</td>
</tr>
<tr>
<td>Mid</td>
<td>e</td>
<td>o</td>
</tr>
<tr>
<td>Low</td>
<td>æ</td>
<td>a</td>
</tr>
</tbody>
</table>

1.4. Outlines of the phonology of Colloquial Egyptian Arabic

1.4.1. Speech sound system
Colloquial Egyptian Arabic has 28 consonant phonemes where fricatives are overriding the stop consonants in number (see Table 1.4). This set includes the four emphatic consonants, i.e., the pharyngealized apicals [d\textsuperscript{5}, t\textsuperscript{5}, z\textsuperscript{5}, s\textsuperscript{5}]. The velar consonants [γ, χ] are realized as the uvulars [k, χ] in an emphatic context, i.e., in the vicinity of any of the emphatic [d\textsuperscript{5}, t\textsuperscript{5}, z\textsuperscript{5}, s\textsuperscript{5}]. The uvulars [k, χ] are referred to as the upper pharyngeal consonants throughout this thesis. The voiceless uvular stop [q] is seldomly used in CEA speech and it is replaced in most of the
cases by the glottal stop [ʔ]. The approximants (glides) [j, w] are considered as vowels in the Arabic phonetics literature, therefore, in our treatment of the consonant inventory in CEA we do not focus on these two sounds as they behave not as typical consonants. The vowel system consists of eight basic vowel phonemes: five long [ii, ee, ææ, oo, uu] and three short /e, æ, o/. The long vowels /ii, ee/ are phonologically reduced to the short vowel /e/, while /uu, oo/ are reduced to the short vowel /o/. These vowels, when they occur in a pharyngealized (emphatic) environment, become centralized due to tongue depression and retraction. Accordingly, two more short vowels, i.e., [i] and [a] and two long vowels, i.e., [ii] and [aa] can be added to the 8 basic vowel as allophones. Table 1.4 lists the consonant phonemes as found in the inventory of CEA, while Table 1.5 shows the distribution of long and short vowels in terms of the tongue height and its horizontal position in the vocal tract. The low back vowel [a] is an allophone of the low front vowel [æ] while the high central vowel [i] is the emphatic allophone of the high front vowel [i]. All these allophones are contextually conditioned by the presence of an emphatic (pharyngealized) consonant in the word.

1.4.2. Stress and syllabic structure

The prosodic aspects of CEA which have relevance to the present study are stress, emphasis as a suprasegmental feature, and phonetic segment quantity, e.g., distinctive vowel length, geminating consonants, etc. Some of the prosodic aspects of CEA are briefly outlined below.

The stress assignment in Egyptian Arabic is correlated with the type of syllable and its position in the word. There are five different syllable forms that can be found in the language. Two short syllables, i.e., CV, CVC and three long syllables, i.e., CVV, CVCC, and CVVC. It is not only the vowel which determines the length of the syllable but also the consonant, especially in a cluster. The ultimate (final) syllable is always bearing the main stress if it is long, i.e., CVV, CVCC or CVVC. If the ultimate syllable is short, CV or CVC, then the antepenultimate is stressed and that requires that both the penultimate and the antepenultimate syllables are short (e.g., /kæ.tæ.bo/, /lɪt'kæ.tæ.bo/ where 1 denotes the stress position). In the remaining cases the penultimate syllable bears the main stress (cf. Harrell, 1957 and Harms, 1981).

1.4.3. Quantity

Quantity is a phonological parameter which refers to the duration of a phonetic segment. The actual duration of a phoneme is the time interval the speaker takes to produce that sound. In Arabic, the duration of vowels as well as consonants is distinctive, i.e., it alters the meaning of a word and it is always indicated with a double symbol. For example, a word as /dææl/ “a letter name” is contrastive with /dæll/ “to inform”. The vowel length is longer in the first word while the consonant is longer in the second word.

1.4.4. Emphasis as a prosodic parameter

As mentioned earlier, Egyptian Arabic has a set of consonants traditionally known as the emphatic or pharyngealized consonants, i.e., /d', t', z', s'/. These consonants are phonetically differentiated from their plain counterparts, i.e., /d, t, z, s/, by having a larger oral cavity and a narrower pharyngeal cavity due to the retraction of the body and the root of the tongue.

2 The double vowel notation is used throughout this book to indicate long vowel.
toward the posterior wall of the pharynx (Jakobson, 1962; Al-Ani, 1970). It has been argued that the feature of emphasis is not confined to a single segment, i.e., the emphatic consonant alone, rather it is spreading to the surrounding segments, both consonants and vowels, thus the acoustic characteristics of the whole utterance will be altered (Ali and Daniloff, 1972). Several studies claimed that the emphasis spreads its phonetic information to the adjacent segments in both directions regardless of the syllabic boundaries, i.e., anticipatory and carry-over types of coarticulation (e.g., Lehn, 1963; Bonnot, 1977; 1979; Ghazeli, 1977). Consequently, the quality of the vowels and consonants surrounding the emphatic segment is altered. This approach treats emphasis (pharyngealization) as a suprasegmental feature. Hence, it looks at the nature of coarticulation from a different perspective, that is, involving the timing of the speech utterance. There are several examples in CEA which support the validity of this approach. For example, in words like /tʰَا.َََاَم.َ/ , /مَا.َََاَم.َ/ , /تَا.ََاَام.َاَاَ/ , the feature of emphasis due to the presence of the pharyngealized consonant /tʰ/, covers the whole utterance. The effect even goes beyond the syllabic boundaries in both directions.

In our study we take into account that when an emphatic segment (e.g., /d̪/) is introduced into an utterance the whole sequence of segments constituting the word will be emphatic. In other words, emphasis is taken as a suprasegmental feature. Hence, emphasis (pharyngealization) is considered to be a feature affecting the entire utterance in both directions, i.e., carryover and anticipatory coarticulation. Therefore, the emphatic vowel /a/ is included as one of the plain vowels constituting the sound system of CEA. Moreover, we observed that /t/ has a similar effect on the vocalic element in some words as that observed for the traditional emphatic consonants. For examples, words like /نااَر/ , /ناار/ , /ناار/ , /سااَااَام.َ/ , /ناااَر/ , /ناااَر/ and /ناار/ display the pharyngealized back vowel /a/. Nevertheless, no minimal pairs were found to be contrastive with the plain /t/ in CEA (Elgendy, 1982).

1.5. The problem of defining pharyngeal articulation

In this section we critically review the studies dealing directly or indirectly with defining pharyngeal articulation as primary or secondary articulation particularly in Arabic.

1.5.1. Pharyngeal articulation and pharyngealization in Arabic

According to the classification available in the literature, Arabic has seven consonants articulated in the back cavity of the vocal tract. Table 1.1 shows the group of back consonants in Arabic as classified into true pharyngeals, uvulars, pharyngealized consonants and laryngeals.

The uvulars /s, ך, q/ are produced by constricting the oro-pharynx. This constriction location can be achieved by bringing the tongue dorsum to approach the uvula. The voiced /s/ and its voiceless counterpart /h/ have a major constriction in the laryngo-pharynx at the level of the fourth cervical vertebrae for a male speaker (see Figure 1.1). In addition, there are two laryngeals /ʔ, h/ in which the major constriction occurs in the glottis itself. The most commonly accepted phonetic description for the manner of articulation for pharyngeal consonants in general is that they are fricatives. However, some views share our opinion which consider pharyngeal consonants as approximant (e.g., Catford, 1965) since the degree of constriction is more similar to a vowel than to a typical fricative consonant.

The Arabic phonemes /s, ך, h/ which are produced in the laryngo-pharyngeal region are thought to have their major constriction, created by the tongue root, at about 3.5 cm above the glottis as presented in the speech of an adult male Lebanese speaker (Klatt and Stevens, 1969;
Delattre, 1974; Ghazeli, 1977). The uvular consonants, which have their major constriction in the oropharyngeal area, created by the tongue dorsum against the uvula, at about 6 cm from the glottis, are included in the class of pharyngeal consonants because they share some spectral properties with the lower pharyngeals. That is, they exhibit a higher F1 which is relatively closer to F2 compared to oral consonants (Klatt and Stevens, 1969, p. 210).

The mechanism used for pharyngeal consonant production is yet far from being established, especially that for the lower pharyngeals. There is still a controversy in the literature regarding the role of the tongue root in forming the structure in the pharynx. Even the few experimental studies which investigated the physiology of pharyngeal articulation, and which were based on lateral X-ray photography (e.g., Al-Ani, 1970; Delattre, 1971; Ghazeli, 1977; Boff-Dkhissi, 1983), could not provide a clear description. It was claimed, based on motion pictures obtained from these films, that the constriction required to produce /ʃ/ or /h/, for instance, is attained merely by active pulling of the tongue dorsum toward the posterior wall of the pharynx. However, it is not sufficient to infer the mechanisms required for creating the constriction in the pharynx from lateral X-ray pictures alone, since using this technique only makes it possible to monitor posterior wall forward displacement but not any inward displacement of the lateral pharyngeal wall. However, what only can be seen in lateral X-ray pictures is the anterior posterior distance. In Chapter 2, we attempt to account for this problem.

Moreover, if the tongue dorsum is the active articulator used to create the constriction, as it is commonly thought, how then can the difficulty encountered by non-native speakers attempting to produce lower pharyngeal consonants be explained? In fact, when a non-native speaker attempts to utter a word containing a lower pharyngeal consonant, the resultant sound is usually not perceptually intelligible as a pharyngeal (Elgendy, 1992, for more details on this issue see Chapter 6). It seems that pulling the back of the tongue backward alone is not adequate to produce the Arabic pharyngeal consonants. Retracting the tongue root or tongue dorsum is a universal articulatory gesture, e.g., production of low back vowels (cf. Maddieson, 1984) which can be tackled by any speaker irrespective of its native language.

Arabic has also another set of speech sounds articulated in the front cavity, viz., /t, d, s, z/ which can be pharyngealized. Pharyngealization, as an added feature on these plain oral consonants, is achieved by depressing the blade of the tongue downward and pulling its dorsum backward so that it approaches the posterior pharyngeal wall. The resulting vocal tract configuration (cf. Figure 1.7) is a larger front cavity, due to the concavity of the tongue blade, and a narrower back cavity due to the retraction of the tongue body (Marçais, 1948; Abramson and Ferguson, 1962 (see Uldall, 1990, for an account on the X-ray film presented in the Abramson and Ferguson study); Ali and Daniloff, 1974; Giannini and Pettorino, 1982). This class of sounds is known in the literature as the “emphatic consonants of Arabic”, i.e., /d̪, t̪, z̪, s̪/ (for an account on an early description of emphatic consonants by medieval Arabic grammarians, see Jakobson, 1962).

1.5.2 Pharyngeal consonants in emphatic environment

In fact, a true pharyngeal consonant can occur in an emphatic (pharyngealized) environment. For instance, in Egyptian Arabic the plain words /ædæl/ “to be justice”, /ææz/ “gas” and /ææh/ “to melt” can be matched with the emphatics /ødæl/ “muscle”, /ɑæz/ “to make angry” and /səah/ “to shout”, respectively. This observation gives rise to the question whether the resulting allophonic variation will be defined as a “pharyngealized pharyngeal” or simply as an “extra” pharyngeal consonant? The problem is interesting because phonological analysis requires phonetic treatment of secondary features of articulation. If a pharyngeal
segment will carry an extra feature, say, “backness”, such that when it is affected by the feature of emphasis, then it is problematic to construct a phonological rule which is able to account for the superimposed phonetic events, i.e., additional “backness”.

From the viewpoint of phonetic description, the distinction between true pharyngeal and pharyngealized consonants has been unclear. Meinhof (1921) speculated that the “compressed” vowel onset observed in the vowel just following the emphatic consonant in Arabic can be due to lowering of the epiglottis so that it covers the laryngeal inlet. Meinhof’s judgment on the state of the epiglottis was derived mainly from a mere observation made on the acoustic effect induced by the emphatic consonant on the following vowel. That is, the upward shift of the first formant and the downward shift of the second formant of the vowel /a/ following an emphatic consonant compared to its plain counterpart. Calzia (1924, p. 59, quoted in Giannini and Pettorino, 1982) also described the articulation of the Arabic emphatics in a manner similar to Meinhof. He further stated that this sort of articulation is accompanied by contraction of the pharyngeal muscles and retraction of the hyoid bone which will cause a decrease in the pharyngeal cavity size.

One ancient study which mentioned the epiglottis and the arytenoids to be associated with the production of the true pharyngeals /ʃ/ and /h/, was made by Avisena (ca. 1010; p. 16) who based his description on anatomical dissection and inspection of strength and size of muscles of the larynx and the structure around it. However, none of the above-mentioned speculations was empirically verified.

In a recent study, based on lateral X-ray pictures taken for an Iraqi speaker of Arabic, it was demonstrated that the epiglottis is actively bending down during the pronunciation of the lower pharyngeal consonants /ʃ, h/ (El-Halees, 1985). Similar results were obtained from nine Egyptian speakers uttering words containing lower pharyngeal consonants. The technique used was fiberoptic video recording to monitor the top view of the upper and lower pharynx (Elgendy, 1987). This study is reported at length in the following chapter.

Bilingual Arabic/Hebrew speakers also have shown similar activities of the epiglottis during the production of the true pharyngeal consonants, emphatic consonants, i.e., /ʃ, d, s, z/, as well as the low-back vowel /a/ (Laufe r and Condax, 1981; Laufe r and Baer, 1988). The technique used to obtain the results reported in these studies was also fibroscopic video recordings of the top view of the lower pharynx. Arabic words containing pharyngeal consonants were used since these consonants vanished from modern Hebrew which only conserved the emphatic set of consonants as those in Arabic.

The question whether the epiglottis plays an active role during speech production has been of minor importance in phonetic research due to the fact that the epiglottis movement is always associated with tongue root movements. For example during the production of low back vowels, the root of the tongue is retracted and depressed on the floor of the mouth. The epiglottis is passively pushed backward. That does not mean that it is receiving any neural commands at that moment. If the epiglottis is proved to be actively participating in the production of speech, particularly during pharyngeal segments, then the design of articulatory models in general will need to undergo considerable changes. However, from a pure physiological point of view, it is possible that the movement of the epiglottis can be independent from that of the tongue, e.g., during swallowing (Bosma et al., 1986). This point is discussed in more details in section 2.4.2 of Chapter 2.

1.6. The structure of the pharynx

The vocal tract conventionally is considered as a three-branch-tube, i.e., the front (oral), the back (pharyngeal and laryngeal) and the nasal branch. The pharynx is a longitudinal
cylindrical tube connecting the nasal and laryngeal cavities together. One part of the cylinder is opened across the vertical axes facing the oral cavity. Figure 1.1 shows a schematic drawing for the pharynx and its structure. The three compartments which comprise the pharyngeal cavity are referred to as the naso-pharynx (hypopharynx), oro-pharynx and laryngeo-pharynx (epipharynx). The naso-pharynx is linked to the oral and pharyngeal compartments via the so-called velopharyngeal port. The pharynx can be constricted at various points by the action of the superior, medial and inferior constrictor muscles. The structure of the pharynx is connected to other muscles controlling activities of the tongue, velum, hyoid, jaw and larynx (for more detailed description on the pharyngeal structure, see Donner et al., (1985) and Bosma et al. (1986). Figure 1.4 shows the muscles of the pharynx and their connections to other articulators.

![Diagram of pharynx muscles](image)

**Figure 1.4. The muscles of the pharynx.**

### 1.7. Mechanism of pharyngeal articulation

There are a number of experimental studies which deal with the production of Arabic pharyngeal consonants in various dialects. Their aim was to provide an account on the mechanism controlling pharyngeal articulation. Some studies were conducted using acoustic analysis methods (e.g., Klatt and Stevens, 1969; Al-Ani, 1970; Adamson, 1981; Elgendy, 1982; Norlin, 1983). Other studies used perceptual analysis (e.g., May, 1979; Alwan, 1989) and some others used physiological methods such as X-ray, EMG or kinematics registrations (e.g., Delattre, 1971; Ghazeli, 1977; Bladon and Al-Bamarni, 1982; Boff- Dekhissi, 1983;
Some of these studies used the cineradiographic technique to obtain dynamic tracings of the vocal tract outlines during the pronunciation of some words containing pharyngeal and laryngeal consonants in Arabic. According to the lateral X-rays tracings of the vocal tract outlines for one Lebanese speaker (Delattre, 1977) and one Tunisian speaker (Ghazeli, 1977), it was noted that the tongue assumes a fixed pyramidal shape (resembling a inverted "V") at a point close to the hard palate. Moreover, the hyoid bone and the larynx were observed to be simultaneously elevated. The larynx is observed to ascend 1.3 cm in superior-anterior excursion (Al-Ani, 1972). During pharyngeal and laryngeal consonants, the jaw displayed an extreme degree of opening, i.e., up to 26 mm on average during /v/ in initial position for some speakers, compared to oral consonants (Elgendy, 1985.b).

1.8. Physiological and anatomical accounts on pharyngeal articulation

In this section some basic physiological and anatomical accounts related to pharyngeal articulation in Arabic are discussed. These accounts are to be found mainly in the textbooks of Zemlin (1968) and Hardcastle (1976).

1.8.1. The Pharynx

The pharyngeal wall is an immovable structure. It does not move away from any medial plane or rotate around a fixed joint as does the jaw, for instance. However, the pharynx can be constricted at various points and to various degrees. The structure of the pharyngeal wall is firmly connected to the larynx, the velum and the mandible by a group of extrinsic muscles (see Figure 1.4).

Several studies presented data showing that the pharynx can be subjected to narrowing or expansion during speech production (e.g., Bell-Berti, 1971; Parush and Ostry, 1986; 1993). There are a number of factors affecting the shape of the pharynx, some are due to mechanical requirements and others are related to aerodynamic conditions. For instance, when any of the pharyngeal muscles, i.e., inferior, medial, or superior constrictor, is activated, a corresponding part of the pharyngeal wall will be constricted. The dilatation of the pharyngeal cavity can normally be achieved by virtue of the increased inter-oral air pressure.

The link between various articulators due to the anatomical connection between the muscles controlling their activities is strong. The movement of one articulator may be coordinated with the combined action of one or more other articulators due to the synergy among muscles performing the motor control commands. In the remaining part of this chapter the anatomical relationship between various muscles and cartilages constituting the synergism and antagonism, which possibly are involved in the mechanism of pharyngeal articulation, will be discussed.

There is a group of muscles which control the shape of the pharyngeal cavity, namely, the constrictor and the levator muscles. The constrictor muscles are the superior, medial and inferior constrictor muscles that originate in the base of the skull, the hyoid bone, the larynx and the lower jaw (see Figure 1.4). These muscles run semicircularly, forming the lateral and posterior wall of the pharynx. During contraction, a forward and downward pull of the pharynx rear wall induces reduction in its cavity size. The contraction of the levator muscles occurs in particular in the lower pharynx, while the upper pharynx is passively compressed (cf. Sonesson, 1970).
One of the muscles which affects the size of the velopharyngeal port is the palatopharyngeus muscle which arises in the soft palate. Its fibers form the posterior pillar of the isthmus of fauces (the port where oral and pharyngeal cavities communicate). This muscle inserts in the lateral pharyngeal wall and the thyroid cartilage, the largest cartilage of the larynx complex. The contraction of this muscle will cause the soft palate to be lowered if the thyroid and the pharyngeal wall are fixed. If the soft palate is fixed, as a result of contraction of an antagonist muscle, the thyroid will be raised, e.g., during swallowing (Zemlin, 1968, p. 307). Accordingly, it can be expected that, if the larynx deliberately is raised, the palatopharyngeus muscle should be passively pulling down the soft palate. This action will lead to an opened velopharyngeal port, hence to a nasal-oral coupling of a certain degree depending on the force of contraction applied on the palatopharyngeus muscle. It is unclear whether it is the extrinsic laryngeal muscles or the palatopharyngeus muscle which are activated so that the larynx is raised during swallowing.

The relationship between the state of the velopharyngeal port and the activities of the pharyngeal muscles is supported by data collected from physiological experiments. One of these experiments (Fritzell et al., 1974) demonstrated that low vowels showed greater electromyographic (EMG) activities of the palatopharyngeus muscle compared to high vowels. Moreover, low vowels were observed to exhibit narrowing of the pharynx which was suggested to be a result of contraction of the pharyngeal constrictor muscles (Parush and Ostry, 1993).

Data on articulatory dynamics of the velum have been reported in a number of experiments showing that the degree of 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 for low vowels (Moll, 1962; Lubker, 1968; Seaver and Kuehn, 1980). The height of the vowel is determined by the tongue position in the vocal tract. The degree of the pharynx size depends on whether the tongue occupies more area in the oral cavity, hence increasing the pharyngeal cavity size, or occupying more area in the pharyngeal cavity and thus widening the oral cavity. Both cases have an impact on the acoustic output signal. One explanation can be that vowels with low F1 (i.e., high vowels) are more sensitive to distortion of F1 than are vowels with a high F1. Thus to avoid that distortion, speakers may keep the velum more elevated (John Ohala, personal communication).

Voicing and manner of articulation also seem to have an effect on the velum position. Data presented on velic movement in French showed that velar height is greater for voiced than for voiceless consonants and that stop consonants are produced with a closed velopharyngeal port (Benguere et al., 1977). Aerodynamic factors may also play a role in determining the degree of velar height. The activities of the soft palate seem to be affected by changes in inter-oral air pressure. Bell-Berti (1976) found that greater activity in the sternohyoid and levator palatini, the muscle which control velum elevation, would lead to an increase in pharyngeal cavity size, thus increasing its volume.

Furthermore, it was observed that the volume of pharyngeal cavity increased during the occlusion period of voiced stops compared to that of voiceless stops in American English. This increase in the volume was interpreted as a result of a mechanism aimed to cause a drop in the supra-glottal air pressure in order to maintain the difference in the transglottal air-pressure which is necessary for the continuation of glottal pulsing during the occlusion period of the stop consonant (Kent and Moll, 1969; Perkell, 1969). Accordingly, it is reasonable to correlate the range of velic movement with the point of constriction along the pharynx and its distance away from the glottis. Based on the above-mentioned account, it seems that the pharynx, in order to be actively involved in articulation, would interact with other articulators, e.g., larynx, epiglottis, jaw and velum.
1.8.2. The Tongue

The palatoglossus muscle is one of the extrinsic muscles of the tongue which arises from the soft palate and inserts into the sides of the tongue. Upon contraction, it may depress the soft palate, or, with the soft palate fixed, it may raise the sides and back of the tongue (Zemlin, 1968, p. 300). So, lowering the soft palate can be attained by activities of palatopharyngeus or palatoglossus. Hence, a link can be established between elevating the back of the tongue and lowering of the velum.

The Styloglossus muscle fibers run between the “styloid process” in front of the ear and the tongue body. Contraction of the styloglossus muscle causes the elevation of the tongue upward. The vertical upward movement of the tongue body is carried out by the styloglossus and the palatoglossus (only if the velum is fixed by the levator and tensor muscles), with the longitudinalis inferior acting in synergy. The convex configuration of the tongue is produced primarily by the hyoglossus which inserts into the lateral margins of the tongue. When contracting in conjunction with the longitudinalis inferior muscle, it brings the back of the tongue in contact with the soft palate. That is, most probably, how the shape of the vocal tract is formed during the production of velar and palatal stops (Hardcastle, 1979, p. 105).

The principal action of the palatopharyngeus muscle is apparent during deglutition, where its contraction guides the bolus into the lower pharynx. Because of the semicircular course of the fibers, this muscle can also act as a sphincter to lower the soft palate and decrease the distance between the posterior faunal pillars. The larynx also may be raised when this muscle is contracted (Zemlin, 1968, p. 300).

So, most probably the convex shape the tongue assumes during the production of the true pharyngeal consonants as can be seen in the X-ray pictures (cf. Delattre, 1971; Ghazeli, 1977; El-Halees, 1985; Ghali, 1989) can be due to activities of two muscles. These muscles are the palatopharyngeus, which causes the tongue body to be curved outward and the styloglossus muscle which raises the tongue upwards.

1.8.3. The Jaw

The lower jaw or the mandible moves in both rotatory and translatory movement around the mandibular condyle (see Figure 1.5). The muscles used to raise the mandible are the masseter, the medial pterygoid and the temporalis. The muscles which lower the mandible are the anterior belly of the digastric, mylohyoid, geniohyoid and the lateral pterygoid. The fibers of the geniohyoid run between the mandible and the hyoid bone. When the mandible is fixed, the geniohyoid (along with the lateral pterygoid, the anterior belly of the digastric and the mylohyoid) pulls the hyoid bone upward and forward. This action causes both the tongue and the larynx to be raised (Zemlin, 1986, p. 294). When the hyoid bone is fixed, the mylohyoid may depress the mandible.

The genioglossus muscle runs from the superior mental spine on posterior surface of the mandibular symphysis. The lowermost fibers course posteriorly back to the anterior surface of the hyoid bone. Besides its function as a muscle of the tongue, the genioglossus can also help to elevate the hyoid bone (and thus the larynx) when the mandible is fixed. The jaw and the tongue movements are coordinated due to the anatomical connection between them and because the tongue is carried by the jaw. Movement of the tongue leads, in most cases, to changes in the position of the hyoid bone (Zemlin, 1968, pp. 146-9).

However, during the speech of English speakers, EMG data showed activities of medial pterygoid and superior lateral pterygoid associated with jaw elevation and activities of the
inferior lateral pterygoid and anterior belly of the digastric during jaw depression (Tuller et al., 1981).

The fibers of both the mylohyoid and the geniohyoid muscles connect the inner surface of the mandible to the hyoid bone. The contraction of these muscles, with the mandible fixed, elevates the hyoid bone and the tongue. With the hyoid bone in a fixed position, it may assist in depressing the mandible (Zemlin, 1968, pp. 142-3). When the mandible is fixed, the mylohyoid together with the posterior belly of the digastric, the stylohyoid and the medial pharyngeal constrictor, helps bulge the tongue up and back for velars. The geniohyoid, when the hyoid bone is fixed by other muscles, serves as antagonist to the thyrohyoid, tilting the hyoid bone and the thyroid cartilage backward such as required for velar and uvular consonants production.

The extrinsic muscles of the tongue which may indirectly contribute to pharyngeal segment production as a secondary articulation are the genioglossus and the hyoglossus. The genioglossus runs from the superior metal spina on the posterior surface of the mandible. The lower most fibers course posteriorly back to the anterior surface of the hyoid bone. The genioglossus may also help in elevating the hyoid bone, and thus the larynx, when the mandible is fixed. Contraction of posterior fibers protrudes the tongue when the mandible is fixed, e.g., during front consonants (Hardcastle, 1979, p. 107). The fibers of the posterior belly of the digastric run between the mastoid process of the temporal bone and the hyoid bone together with the stylohyoid muscle. Contraction of the digastric muscles (anterior and posterior bellies) raises the hyoid bone. If the hyoid bone is fixed, it may assist in depressing the mandible. Contraction of the anterior belly of the digastric alone draws the hyoid bone up and forward, while contraction of the posterior belly draws the hyoid bone up and backward. Both actions are important for the first and second stages of swallowing. If both bellies are contracted, the hyoid bone is drawn directly upward, thus elevating the base of the tongue, which during the oral phase of swallowing is pressed against the hard palate (Zemlin, 1968, p. 141). The greater cornua of the hyoid bone are included in the lateral pharyngeal wall (Donner, Bosma and Robertson, 1985). On the other hand, the body of the hyoid bone attaches to the base of the tongue. Accordingly, it is expected that muscular activities operating on the jaw and the hyoid bone may also affect the state of the tongue and vice versa.

1.8.4. The Larynx

Since the pharyngeal consonants are created at a very close distance from the glottis, it is useful to give a brief account on the mechanism of the larynx. The three main cartilages constituting the larynx complex are the thyroid, cricoid and the arytenoid pair. The epiglottis is attached to the thyroid by connective tissues. All these cartilages are connected together and they interact while moving, depending on the activities performed, e.g., breathing, swallowing, talking, etc. The muscles which approximate the arytenoids cartilages are the oblique and the transverse fibers of the interarytenoids which run between the two arytenoids. When these muscles contract, they adduct the vocal folds by bringing the apexes of the arytenoids together. They also help the aryepiglottis muscle to close off the vestibule of the larynx (Zemlin, 1969, pp. 151-153). The thyroarytenoid muscle, which runs between the thyroid and the arytenoids cartilages, inserts in both the interarytenoid muscles and some of its fibers into the posterior cricoarytenoid muscle. The contraction of this muscle will pull the arytenoids upward to mount the cricoid cartilage.
Figure 1.5. The muscles controlling the movement of the mandible and the direction of their action: (1) the Temporalis; (2) the external Pterygoid; (3) Masseter and internal Pterygoid; (4) Digastric; (5) Infrahyoid.

Figure 1.6. Schematic drawing represents the extrinsic laryngeal muscles and the direction of their actions.
This mechanism causes the vocal folds to be shortened in length and hence relaxed (Zemlin, 1969, pp. 148-155). It should be noted that the control of laryngeal muscles affects, to a great extent, the activities of the vocal folds which in turn determine the properties of the source signal. Figure 1.6 shows a schematic drawing which represents the extrinsic laryngeal muscles and the direction of their actions.

1.8.5. Relation between laryngeal activities and jaw position

Some studies have reported that the voiced pharyngeal consonant /S/ is characterized by a remarkably low value of the fundamental frequency (Ohala, 1972; Elgendy, 1982). Also, the jaw position during the production of the pharyngeal consonants in particular has been shown to be extremely lower than during non-pharyngeal (oral) consonants (Elgendy, 1985). It is part of the present study to search for a physiological explanation to the characteristics of the acoustic signal associated with the production of pharyngeal consonants and also to account for the specific behavior of the jaw observed during pharyngeal articulation, i.e., extreme degree of lowering.

There are some studies which point that interaction between laryngeal activities and the direction of mandibular movement during speech is possible. For instance, the sternohyoid muscle has been shown to be actively involved in lowering the fundamental frequency of voice (F0), especially for speech utterances requiring lowering of the jaw and fixation of the hyoid bone (Ohala and Hirose, 1969; Sawashima et al., 1982; Kori et al., 1990).

Jaw depressing probably involves fixation of the hyoid bone since the digastic muscle, which is mainly responsible for opening the jaw, loops around the hyoid bone. The contraction of the digastic muscle would tend to pull the hyoid bone upward if its movement is not opposed by contraction of the sternohyoid muscle (see Figure 1.6). Activities of the sternohyoid, revealed by EMG registrations, were inhibited during the closing phase of jaw movement in the speech of a Japanese speaker uttering the word /atari/ (Ohala and Hirose, 1969). Associating jaw lowering with a lower F0 can be taken as an explanation to the observed variations in the intrinsic vowel fundamental frequency found in some languages, i.e., open vowels have lower F0 than that for closed vowels.

However, some studies take these findings to support the “tongue-pull” hypothesis suggested by Lehiste (1970), Ohala (1973) and Ewan (1975). This hypothesis assumes that the tongue, when elevated for the production of high vowels, pulls the hyoid bone and the larynx upwards, so an increase of the vocal cord tension occurs leading to a higher F0, Ohala (1973) claimed that there is a correlation between the tongue height and the degree of tension in the vocal cords. According to his hypothesis, the elevation of the tongue (hence also the jaw) during /i/ for instance, will cause the hyoid bone and the larynx to be pulled upwards, as they are connected to the tongue, resulting in an increase of the vocal cord tension and consequently leading to a higher F0.

EMG activities of the cricothyroid muscle have been shown to be responsible for raising F0 (Sawashima et al., 1982; Vilkman et al., 1989). Activities of the cricothyroid were also associated with the production of segments which require the jaw to be more close (Sawashima et al., 1982). In a study combining EMG, X-rays and anatomical methods, Zenker and Zenker (1960) established a relation between activities of the cricopharyngeal muscle and shortening of the vocal folds. The cricopharyngeal muscle acts as an antagonist to the cricothyroid muscle by which, with the larynx in a low position, the cricoid is rotated to the front, causing the vocal folds to relax. These muscular activities are part of a functional chain of muscles including the arytenoid-epiglottis, hyoid-mandible and inferior fibers of the genioglossus-mandible which was observed to play a role in shortening the vocal folds
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(Zenker and Zenker, 1960). These muscles connect the jaw, the tongue, the hyoid and the larynx, thus their activities are expected to interact.

Lower pitch was found to be associated also with lowering of the whole laryngeal structure which in turn may pull on the hyoid bone (Honda et al., 1993). This finding supports the view that the control of fundamental frequency of voice may be attained not only by horizontal (anterior-posterior) movements of the vocal fold but also by vertical movement of the laryngeal cartilages (Ohala, 1972). So it seems that there are more than one mechanism which can be used to achieve shortening of the vocal folds as a phonetic goal.

The voiced pharyngeal consonants, i.e., /ɡ, k/, are characterized by considerably lower fundamental frequency (Elgendy, 1982; Alwan, 1986). The mandible during the lower pharyngeal consonants /ɡ, k/ assumes extreme degree of jaw lowering compared to that during the production of the oral consonants (Elgendy, 1985). During the production of the pharyngeal consonants, the larynx was found to be raised 1.3 cm relative to its rest position (Al-Ani, 1972). All these features occur simultaneously during the production of a pharyngeal consonant. To relate these characteristic articulatory gestures to a specific mechanism seems to be difficult. It seems that in order to examine the association between lowering the jaw, lowering F0 and raising the larynx, more specifications about the muscles involved are required. Therefore, our investigation bears on the issue of predicting the muscles involved in pharyngeal articulation.

The pharyngeal wall can be subjected to various degrees of displacement at different points along the pharyngeal cavity. It has been demonstrated in a number of studies (Skolnick, 1970; Shprintzen et al., 1974; Zagzebski, 1975; Ryan et al., 1976) that velum movements interact with contraction of the upper portion of the lateral pharyngeal wall. Thus elevating the velum may involve contraction of the superior constrictor muscles of the pharynx. Moreover, these studies showed that the pharyngeal wall at various points was observed to display different degrees of displacement depending on the mode of activity, i.e., breathing, blowing, swallowing or during the production of speech sounds. Though different experimental methods have been used, the findings of these studies all indicate that muscular activities of the pharynx are coordinated with activities of other moveable articulators, e.g., larynx, jaw, velum, tongue and lips.

From the above account on the muscles which might contribute synergistically in controlling the movements of the tongue, the mandible, the hyoid bone and the larynx complex, it can be speculated that the group of muscles which can be involved during pharyngeal and laryngeal articulation is possible to be inferred. One way to achieve a better understanding of the mechanism controlling pharyngeal segment production is by comparing the shape of the back cavity of the vocal tract with the output acoustic signals associated with their production. The present investigation is intended to study the dynamics of the velum, the larynx and the jaw during the production of pharyngeal segments in order to provide such an account.

1.9. Coarticulation

In this section we briefly discuss the problem of coarticulation in speech production and how it can be related to pharyngeal articulation.

1.9.1. Sources of coarticulation

The vocal tract can be seen as a single non-homogeneous tube composed of three regions, i.e., nasal, oral and pharyngeal cavities, which are contiguously coupled together. The resonance
modes of the air column within these cavities during speech production are sensitive to local narrowing or expansion. All parts of the vocal tract contribute in varying degrees to each mode. The shape of the tract is determined by the positions taken by various articulators such as lips, tongue, jaw, velum and larynx during a given speech utterance.

Speech sounds are the products of a series of neuromuscular activities conducted by the motor system in order to manipulate the movement of various articulators according to a cognitive plan. The configuration of the vocal tract at a given moment in time will be the output of the execution of a specific set of motor commands leading to what is referred to as the articulatory gesture. Movement of the articulators may widen, constrict or elongate the vocal tract which in turn will affect its volume and length. For instance, the length of the tract increases when the larynx is lowered or the lips are protruded, while constricting the pharyngeal muscles will decrease the volume of the pharynx.

Thus any modification of the overall configuration of the vocal tract causes changes in its cross-section area and consequently alters its resonance frequencies. In normal speech different mechanisms are used to create acoustic regulation, adjustment or adaptation to the proper degree required to achieve optimal, or just enough, acoustic contrast among the constituents of the speech signal flow. Acoustic modulation affects the auditory channel of both listener and speaker during the process of speech communication and thus it represents an important parameter in the study of speech.

To establish a comprehensive account of the production of various speech sound categories, it is essential to find out about the magnitude of acoustical differences ascribed to any particular articulatory variable. The nomograms published in the classical work introduced by Stevens and House (1955) and Fant (1960) represent a complete description of the acoustic properties correlated with various articulatory gestures in terms of the cross-section areas and the associated formant frequencies. In natural speech, however, formant frequencies are also determined by the interaction of dynamic movements of various articulators (e.g., lips and tongue blade movement in the oral cavity; tongue root movement in the lower or upper pharynx; vertical larynx movement, etc.). A typical case of such interaction is that of pharyngeal articulation. We assume that the changes in the shape and size of the pharyngeal cavity depend highly on the movement of other articulators.

Since articulators have different masses and sizes, and the mass is correlated with inertial factors, the time the muscles take to react to motor commands will vary among various articulators. Muscles also have different sizes and hence vary in their speed of moving. Inertia is the tendency of matter to remain at rest if at rest, or, if moving, to keep moving in the same direction, unless affected by some outside force. Articulators would resist commencing moving when muscle force is abruptly applied and resist slowing down or stopping when the accelerating force is removed. When decelerating only frictional forces are remained. That is, articulatory gestures may overlap in space and time because of these mechanical and inertial constraints. The existence of such constraints certainly delimit the capacity of the motor system.

The overlap in space and time between articulatory gestures in a sequence is called coarticulation. This overlap may cause one of the sounds to lose some of its features, by assimilating to a following or a preceding sound, or to acquire additional features borrowed from any of the surrounding sounds in the utterance. It has been suggested that the co-production of several articulatory gestures is possible as long as no conflict with the surrounding sounds exists (Moll and Daniloff, 1968). Different articulatory gestures can be used to produce similar acoustic output. This phenomenon has been demonstrated by Abbs (1977) to which he referred as "motor equivalent". The motor equivalence principle indicates
that the perceptual output is by and large the goal of the communicative message transmitted from a speaker to a listener.

Coarticulation can originate from other sources than the variations in the timing resulting from mechanical-inertial factors mentioned above. For instance, articulators can receive pre-programmed neural commands to occur simultaneously. In such a case, the articulator movements are often deliberately initiated far in advance of the sound intended for it. Accordingly, some of the features of that sound will be smeared with the sounds occurring prior to it. This phenomenon is known as anticipatory coarticulation (or right to left coarticulation). An example of the anticipatory type of coarticulation is velum lowering long before a nasal consonant occurs in an utterance. In American English, the velum was found to be already lowered during the initial two consonants and following vowels in a /CCVBN/ sequence (where N is a nasal consonant). This only occurs as long as the CCV part does not include any sound which requires a complete closure of the velopharyngeal port, e.g., /s/ (Moll and Daniloff, 1971).

On the other hand there are other cases where features of an initial sound in an utterance are carried over to the following sounds as long as the features of that sound do not conflict with the following sounds. This type of articulation is called carry-over coarticulation (or left to right coarticulation) because the feature of the initial sound in a sequence is transferred to the following segments and is blended with the features of those other segments. The fact that some articulators coarticulate to a greater range than others on one hand, and the phonetic context on the other, are two variables which are considered to be important for determining the extent of coarticulation. Another variable can be that of speaking rate (e.g., Stevens and House, 1963; Van Son, 1991).

The organs which are involved in the speech process are limited in terms of their movements direction and speed. This fact causes the articulators to undergo certain constraints of various types. Some of these constraints are mechanically-based limitations applied on the articulator speed and range of movement, e.g., range of jaw opening, rapidness of tapping the tongue tip, the degree of extent of lip protrusion, etc. Due to these articulatory constraints, three cases can arise which affect the cognitive process of normal speech communication: 1) The constraints are not realized by the speaker’s cognitive plan and not compensated for during performing speech. 2) The constraints affecting the articulators movement are realized by the speaker and still are inherently considered in the planning scheme of articulation during language evolution. 3) The speaker is aware of the type and range of constraints and compensates for that by avoiding or simplifying the conflicting articulatory gestures when they are possible to occur in combination.

The first case seems to be unrealistic, since there are numerous evidences showing that speakers do control most of their motor activities during speech production. For instance, the speaker compensates for the effect resulting from conflicting gestures by applying phonological processes such as assimilation, deletion, etc., to overcome the difficulty. That the speaker is aware of the limitations of the speech system implies that the choice of compatible successive constituents in the speech string is based on the aim to enhance the perceptual contrast within the acoustic signal. Hence, the acoustic consequences of each individual articulatory gesture are considered in the motor planning as in the second case. The third case is when the timing organizing the series of speech sound units is considered in the articulatory and the motor planning prior to the production process of a speech utterance. Timing realization in the cognitive plan phase is basic when considering coarticulation as preplanned articulatory process. In order to define coarticulation in the pharynx, it is necessary to examine these aspects which are related to the timing as well as the serial ordering of speech sound constituents.
Coarticulation as an existing phenomenon is a crucial issue in understanding the speech motor control system. Coarticulation can be defined according to either one of the following two views. The first view holds that coarticulation is considered as caused by mechanical-inertial factors affecting the articulator’s dynamics by putting restrictions on the range and speed of articulator movements. Accordingly, the sound system which a given language makes use of, is built up of arbitrarily selected sound units which are bound to a specific set of grammatical rules to enable verbal communication (e.g., Daniloff and Hammerberg, 1973). The other view considers coarticulation as a pre-planned articulatory process operating in such a way that the speaker is aware of the effect of interaction of the constituents of a speech utterance. Sound units, according to that view, are selected to preserve the natural tendencies and properties of the dynamical aspects of the motor system controlling articulators movements. That is, the content of the articulatory plan is a well-defined set of dynamical gestures controlled both in time and space. These two views are discussed in the following section (see Fowler, 1981 for a discussion on that topic).

1.9.2. Models of coarticulation

Any model of speech production represents an attempt to account for the control of speech production mechanism as a whole, or any part of that mechanism. A complete model must recognize, however, the interactions of respiratory, phonatory and vocal tract components which govern the process of speech production. Moreover, a model should also consider other processing levels such as the neuromotor level, the dynamics of muscular movements and the dynamics of cavity size variations. A comprehensive model should also be compatible with the knowledge concerning the perceptual constraints characterizing the human hearing apparatus.

The current models which attempt to account for the coarticulatory observations all seem to share the search for a basic unit of speech production. Some theories take the articulatory syllable as the basic unit, e.g., Kozhevnikov and Chistovitch (1965). The syllable, roughly, is any number of consonants and a vowel, whether long or short vowel. Accordingly a speech utterance is a composite of one or more syllables strung together.

Other models take the feature bundle specific to each phoneme, whether a consonant or a vowel, as their basic unit of a speech utterance, e.g., Daniloff and Hammerberg (1973). Feature bundles are also considered in some other models as the end product of a spatial target the articulator seeks to reach from one moment to the other (MacNeilage, 1970). In this model, the speech plan is organized in such a way that the articulators move from one specified feature bundle to the next. The speech plan can fail due to, for instance, perturbation factors such as an incompatible consonantal elements within the phoneme sequence. When the execution of the plan fails at a given point along the utterance, the features are spread through the string of phonemes constituting the utterance. Transitional sounds result from the abrupt changes in the spatial configuration of the vocal tract as due to successive motor commands. In order to avoid these transitional sounds, the articulators, trying to accommodate the conflicting specifications assigned for each target position, violate the canonical form of the specified feature bundle, i.e., the phoneme. This will produce allophonic variations of the intended canonical form as manifested in the output acoustic signal. A representative of that view is the “feature spreading” model in which the phoneme is considered as having a bundle of distinctive features. The features spread to the adjacent phones as long as the features of that sound do not conflict with the features of the surrounding phones (Keating, 1980). One crucial principle shared by these models is that they take the extrinsic timing governing the speech organization as an assumption.
However, there are other views which consider the speech planning as involving direct control of the temporal organization of speech utterance at higher level of the speech planning, i.e., intrinsic timing of articulatory events. For instance, Fowler (1981) suggested that the two main classes of articulatory gestures, i.e., consonants and vowels are the products of different, but coordinated, neuromuscular systems. In the co-production model proposed by Fowler (1981), the temporal patterns of speech utterances are preplanned and the timing parameter controlling various articulatory events within an utterance is issued internally. That is, consonant and vowel sequences are co-produced in a co-ordinative manner (Fowler, 1981).

1.10. Statement of the problem

The present investigation deals with pharyngeal articulation in general with a focus on its dynamic aspects as observed in spoken Egyptian Arabic. In Arabic, the pharynx is used to produce distinct phonemes both as primary as well as secondary place of articulation. The primary articulation produces the true pharyngeals while the secondary articulation produces the pharyngealized consonants. This section outlines the problem of defining pharyngeal articulation and coarticulation. We attempt to provide an account on the nature of coarticulation in the pharynx as exemplified in normal pharyngeal articulation in Arabic.

The pharyngealized consonants are produced by retracting the back of the tongue and depressing its body downward in order to decrease the size of pharyngeal cavity. For this set of sounds, the tongue is the major articulator used to create the constriction in the back cavity of the vocal tract.

The true pharyngeal consonants, on the other hand, are attained, we assume, by a different mechanism, since they are highly more difficult to produce than the pharyngealized consonants. However, the phonetic description available in the literature on the true pharyngeal consonants as a class of speech sounds is ambiguous and for the pharyngealized consonants it is even bewildering (cf. for instance, Marcai (1948), Ali and Daniloff (1972), Bonnot (1977), Giannini and Pettorino (1982), Al-Ani (1970) and Norlin (1987). The reason for that confusion in describing the two different types of articulations is the similarities they share regarding their spectral properties, i.e., the first and second formant frequencies are closer to each other. It is implicitly understood from that description that the active articulator which creates the stricture in the pharynx is the tongue dorsum. The reason for this belief is the resemblance of the spectral distribution for low back vowels.

The auditory perceptual impression a trained ear can get when listening to words containing true pharyngeal segment, suggests that also some degree of nasal coupling may exist. By listening carefully to the intonation pattern of phrases containing a voiced pharyngeal consonant, a remarkable drop of the F0 contour at the moment the pharyngeal segment is produced can be realized. The acoustic signal shown on a sound spectrogram associated with the production of a typical true pharyngeal consonant, e.g., /?/ compared to that of the preceding vowel may indicate the presence of constriction in the larynx itself (Elgendy, 1982). Figure 1.7 represents a wide band and an intensity spectrogram of a typical true pharyngeal consonants /?/ as uttered by a native male Egyptian speaker of Arabic. Note the lack of spectral energy in the high frequency region and the low fundamental frequency of the voice as indicated by the wide separation between vertical striations (see also Figure 4.1 for F0 contour of some words contain the voiced pharyngeal consonant).

The anatomical connection of the pharynx with other parts of the vocal tract suggests that the larynx, the hyoid bone, the velum and, probably, the lower jaw can be affected by the active contraction of pharyngeal muscles.
What is evident is that the production of the true pharyngeal consonants, /ʕ/ and /h/ for instance, can not, by any means, be as simple as the production of, e.g., low back vowels, or the pharyngealized (emphatic) consonants. Accordingly, it is reasonable to presume that the pharynx can be actively involved in the production of such consonants. In other words, pharyngeal articulation can be more complex than it is thought to be. In support of this claim we collected some observations obtained from various fields of linguistics, i.e., sound change, speech pathology, language acquisition, second language learning, phonology and phonetics.

1.10.1. Pharyngeal articulation and sound change

Pharyngeal consonants are difficult to produce by non-native speakers. It also seems that pharyngeal segment production is relatively complex even for native speakers. A general observation which may support the notion of the complexity of pharyngeal articulation in Arabic is the relatively long acquisition time native speakers need in order to master the production of pharyngeal articulation in normal cases (cf. Omar, 1973). Moreover, it is possible to notice the difficulty non-native speakers exhibit in learning or trying to imitate the production of pharyngeal consonants as novel sounds. Nevertheless, the occurrence of pharyngeal consonants within the Arabic language seems not to be rare (cf., e.g., Tomiche, 1964; Mousa, 1972). For instance, the voiced pharyngeal /ʕ/ is ranked among the five most frequent consonants in Egyptian Arabic (Elgendy, 1993). In general, surveying the literature shows that not much work has been done on pharyngeal articulation as a linguistically significant sound unit. As we mentioned earlier, it is a fact that pharyngeal consonants were observed to be rarely used in the sound inventories of languages of the world.

In Egypt there are several linguistic communities which are bilingual. They have been created as a result of immigration from non-Arabic speaking countries to Egypt some hundred years ago, e.g., Armenia, England, France, Italy, etc. A common phenomenon among the
bilingual people of Greek and Italian origin in Egypt is the replacement of the pharyngeals /ʕ/, h/ with a glottal stop and a voiceless velar fricative /ʔ, x/, respectively. The same observation holds true among the non-native speakers when they try to pronounce Arabic words containing one or more of the lower pharyngeal sounds (Elgendy, 1992). It is often observed that a non-native speaker of Arabic would utter the proper noun /ʔæhmaed/ as /axmad/ substituting the lower pharyngeal /h/ by the velar sound /x/ or in other cases by the voiceless laryngeal fricative /h/. If the word contains the voiced pharyngeal /ʕ/, the speaker replaces it with a glottal stop or simply prolongs the vowel following it. Moreover, a trained phonetician who has Arabic as native language would feel the relatively greater effort when uttering a true pharyngeal segment compared to, say, labial or dental segments. It is worth mentioning that in modern Hebrew the lower pharyngeal consonants /ʕ, h/, originally existing in all members of Semitic language family, are replaced with the glottal stop and the voiceless laryngeal fricative, respectively.

Besides the perceptual judgement of an experienced ear that would notice the presence of some degree of nasalization accompanying pharyngeal consonant production, there are some observations which point to a possible connection between nasal and pharyngeal articulation. In some regional dialects in certain areas of the Arabian Gulf, e.g., contemporary Iraqi Arabic of Baghdad, we observed that the voiced pharyngeal /ʕ/ in a word like /ʔɑʕtə/ “he gave” is replaced with a nasal consonant, i.e., the word will be pronounced as /ʔɑŋtə/. The explanation of such a relationship between nasal and pharyngeal articulation seems to be difficult to reach. It is our intention to attempt to account for this possible connection between nasal and pharyngeal articulations. The pharynx, being coupled to the nasal, oral and laryngeal cavities, has a strong anatomical link with various articulators in the vocal tract. In fact there are several observations which point to a possible interaction between nasal, pharyngeal and laryngeal articulation and which are part of the motivation for the present study.

One more observation which points out to a possible interaction between pharyngeal and nasal articulation, is obtained from a speculation based on diachronic sound change comparison. It has been speculated that a pharyngeal consonant can phonetically develop, over a certain period of time, into a nasal sound (Hetzron, 1969). This speculation was promoted by an observation made by P. Delattre on Arabic pharyngeals (see Hetzron, 1969). Delattre observed that the X-ray pictures made for one Iraqi subject manifested a velic lowering during the production of lower pharyngeals. Hetzron attempted to explain the non-etymological /n/ found at the end of an initial syllable in certain words in East Gurage, a Semitic Ethiopic language, as a process of diachronic sound change passed through two different stages. When the Cushites, tribes unrelated to Semitic language community living in the east Sidomo area, first tried to learn the pharyngeal segments /ʕ, h/ as novel sounds in words imported from the Semitic language, the perceptual (acoustic) impression they received was a nasalized laryngeal /ʔ/ or /h/. In a later period of time, nasalization is induced by the consonant on the following vowel which further decomposed into a combined vowel and nasal consonant. This process of sound change can be represented by the phonological rule below (V stands for any vowel, n for a nasal consonant, C for any consonant, ~ for nasalization and # for a syllable onset):

\[
# [ʕ, h]+ V + C \rightarrow #[ʔ, h] + V + C \rightarrow #n + V + C
\]

In general, vowel nasalization was observed in several languages to occur often in the environment of laryngeal consonants (Matisoff, 1975). What makes a pharyngeal consonant to be replaced with a nasal consonant? Is it because the aerodynamic requirements for a
remote place of the constriction in the pharyngeal cavity are not severe enough to keep the
velopharyngeal port closed? Or is it purely a mechanical reason that causes the velum to be
lowered? In this study we attempt to answer these questions and to offer an account on the
possible link between the pharyngeal and nasal articulation.

1.10.2. Pharyngeal articulation in pathological speech

Pathologically, the pharynx and larynx can be manipulated to compensate for the inefficiency
of producing speech sounds articulated in the oral cavity. It has been demonstrated that
American (Trost, 1981) and Japanese (Honjo and Isshiki, 1971) children with a cleft palate
tend to substitute the target phoneme /k/ or /t/ by a sound articulated in the pharynx. The cleft
palate patients usually suffer from excessive hypernasality. This defective articulation, which
is attained by pressing the back of the tongue against the posterior wall of the oro-pharynx,
was referred to as "unvoiced pharyngeal stop". In another study (Kawano et al., 1985), the
term "laryngeal fricative" was used to describe the same phenomenon observed for Japanese
cephalic palate patients. A similar maneuver was also observed (Ericsson, 1987; p. 75) regarding
Swedish cleft-palate children. The term "supplementary pharyngeal noise" (coined by B.
Lindblom) was used by Ericsson to describe the superimposed pharyngeal fricative sound
concomitant with sounds produced at the ordinary place of articulation in the oral cavity.

Moreover, if the tongue was partially or totally excised from patients for medical reasons,
still speech is possible with the help of other articulators. It has been demonstrated that
compensatory articulation for total glossectomy is achieved by means of exaggerated use of
the jaw, pharynx and epiglottis (Morish, 1984). In another study on the speech of American
English glossectomized speakers, the voiced velar stop /q/ was found to be compensated by a
pharyngeal constriction, with slight inward bulging of the retropharyngeal pharyngeal wall (Skelly
et al., 1971, p. 111). The acoustic result of the substituted sound resembles that of the German
glottal stop.

Another observation in which a relation between nasal and pharyngeal articulation can be
realized is taken from the area of language disorders. One of the most common speech defects
among the Egyptian patients of dyslalia is known as "pharyngeal sigmatism". Dyslalia as a
speech disorder is defined as the persistence of isolated phonological errors in a relatively late
period of language development. The defective segment the patient tends to produce is a
nasalized, pharyngealized dental fricative [s̩] instead of the normal phoneme, i. e., the plain
voiceless dental fricative [s] (Kotby and Barakah, 1979). For a normal Arabic speaker, only a
pharyngealized [s̩] can be nasalized but not the plan [s].

It would be reasonable, then, to consider the above-mentioned observations from both
normal and pathological speech as indications of possible connections between
velopharyngeal orifice area and point of constriction along the pharynx. These observations
may also lead to the following question: What could be the common factor (if any) between
pharyngeal, laryngeal and nasal articulation? The present investigation attempts to offer an
answer to that question.

1.10.3. Jaw and pharynx interaction

Data on jaw dynamics associated with the production of pharyngeal consonants showed that
the mandible is assigned various degrees of elevation depending on the constriction location
in the pharyngeal cavity. That is, /s/ has a lower jaw position than /h/ and the upper
pharyngeal /ts/ has a lower jaw position than /χ/. The degree of elevation is shown to be
depending on the position of the pharyngeal segment in the word. The jaw maintains its assigned position for the pharyngeal segment even during the following vowel in intervocalic position but not initially or finally in a word (Elgendy, 1985.b). Accordingly, it can be assumed a priori that the constriction in the pharyngeal cavity is executed according to a more complex program than just retracting the back of the tongue. The interaction between 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. The result is an excessive nasal emission of air (hypernasality), which in turn will affect the acoustic quality of the intended speech segment.

1.10.4. Pharyngeal co-articulation

In defining pharyngeal co-articulation, it seems essential to consider the anatomical and physiological links among other articulators interacting with pharyngeal movements. Bearing in mind the acoustic and perceptual consequences of any neuromuscular activities pertaining to the vocal system and the fact that not all articulators coarticulate in all contexts, it appears unavoidable to examine the behavior of the pharynx in relation to other movable articulators. Articulatory gestures overlap in space and time because of the contextual influence of phonetic segments in a string on each other. This overlap gives rise to modifications of the acoustic realization of a basic speech sound unit, i.e., a segment (whether a phoneme or a syllable), depending on the phonetic context.

The pharyngeal wall is a fixed structure that does not move away from any medial plane or rotate around a fixed joint as the jaw for instance. However, its structure is firmly connected to the larynx, the velum and the lower jaw by a group of extrinsic muscles. It is an accepted fact that the pharynx can be subjected to narrowing or expansion during speech production for various reasons. When any of the pharyngeal constrictor muscles is active a corresponding part of the pharyngeal wall will be constricted, while the dilatation of the pharyngeal cavity can be achieved by virtue of the increased interoral air pressure.

The larynx and the lower jaw also are apt to interact with pharynx movements. The upper and lower pharyngeal consonants include voiced as well as voiceless segments. The mechanism of their production must consider the glottis shape required to generate vibration of the vocal folds and/or to create the suitable fricative noise at the source. Furthermore, data on jaw displacement during the production of various pharyngeal consonants showed that the voiced pharyngeal segments have a lower jaw position than their voiceless counterparts, e.g., /\', u/ have lower jaw position than /h, \', respectively (Elgendy, 1985.b).

In addition, tongue height seems to influence the degree of constriction in the pharynx. Several studies have presented measurements of lateral wall displacement at levels below the hard palate showing more inward displacement for low-back vowels than for high-front vowels (e.g., Kelsey et al., 1969; Minifie et al., 1970; Parush et al., 1986). It has been demonstrated that the degree of velar elevation, hence the size of pharyngeal stricture, varies directly with tongue height for oral segments (Björk, 1960; Lubker, 1968; Fritzell, 1969; Bell-Berti and Hirose, 1975). These data may indicate that a relation can be established between the constriction location across various points along the pharynx and the degree of velic opening and/or active pharyngeal wall displacement during the production of various pharyngeal segments. Pharyngeal coarticulation can be defined as the interaction between pharyngeal activities and various other articulator movements due to anatomical links.
1.11. Review of the literature on pharyngeal articulation in Arabic

In this section we critically review the research work made on pharyngeal articulation in Arabic and reported in the literature. In these data we search for the points discussed in section 1.10 below, mainly, nasality associated with pharyngeal consonant production, jaw behavior, tongue shape and the epiglottis envolement.

1.11.1. Physiological data on pharyngeal consonants production

There are two main sources by which data on Arabic pharyngeal articulation can be obtained, i.e., X-ray pictures for physiological data and acoustic/perception data. This section deals with the physiological study on pharyngeal articulation in Arabic while the acoustic/perceptual studies will be reviewed in the next section. One of these sources is the one that makes use of the cinefluorographic technique (X-rays motion pictures) to obtain pictures of the shape of part or whole of the vocal tract. There are several studies which investigated the shape of the vocal tract during the production of pharyngeal and/or pharyngealized consonants. Some of these studies also included the laryngeal and uvular consonants among the sounds investigated. A critical review of these studies is given below.

Table 1.6. Physiological studies dealing with pharyngeal articulation in Arabic. The table shows the author name, publication year, number of speakers reported (sp), the version of Arabic used by the speakers, the sounds examined in each experiment and the type of the technique used.

<table>
<thead>
<tr>
<th>Author name, publication year</th>
<th>sp</th>
<th>version</th>
<th>sounds</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marçais (1948)</td>
<td>1</td>
<td>Algerian</td>
<td></td>
<td>X-rays</td>
</tr>
<tr>
<td>Abramson and Ferguson (1962)</td>
<td>3</td>
<td>Syrian</td>
<td></td>
<td>X-rays</td>
</tr>
<tr>
<td>Ali and Daniloff (1972)</td>
<td>3</td>
<td>Iraqi</td>
<td></td>
<td>X-rays</td>
</tr>
<tr>
<td>Bonnot (1977)</td>
<td>1</td>
<td>Saudi</td>
<td></td>
<td>X-rays</td>
</tr>
<tr>
<td>Giannini and Pettorino (1982)</td>
<td>1</td>
<td>Iraqi</td>
<td></td>
<td>X-rays</td>
</tr>
<tr>
<td>Al-Ani (1970)</td>
<td>1</td>
<td></td>
<td></td>
<td>X-rays</td>
</tr>
<tr>
<td>Delattre (1976)</td>
<td>1</td>
<td></td>
<td></td>
<td>X-rays</td>
</tr>
<tr>
<td>Ghazeli (1977)</td>
<td>1</td>
<td></td>
<td></td>
<td>X-rays</td>
</tr>
<tr>
<td>Wood (1979)</td>
<td>4</td>
<td></td>
<td></td>
<td>X-rays</td>
</tr>
<tr>
<td>Boff-Dkhissi (1983)</td>
<td>1</td>
<td></td>
<td></td>
<td>X-rays</td>
</tr>
<tr>
<td>Al-Bamerni (1983)</td>
<td>3</td>
<td></td>
<td></td>
<td>Transillumination</td>
</tr>
<tr>
<td>Elgendy (1987)</td>
<td>9</td>
<td></td>
<td></td>
<td>Video Fiberscopy</td>
</tr>
<tr>
<td>Ghali (1989)</td>
<td>1</td>
<td></td>
<td></td>
<td>X-rays/Fiberscopy</td>
</tr>
<tr>
<td>El-Halees (1989)</td>
<td>1</td>
<td></td>
<td></td>
<td>X-rays</td>
</tr>
<tr>
<td>Sakai et al. (1995)</td>
<td>3</td>
<td></td>
<td></td>
<td>X-rays/Fiberscopy</td>
</tr>
</tbody>
</table>

The studies which oriented their approach to obtain lateral X-ray still pictures, i.e., Abramson and Ferguson (1962), Al-Ani (1971), Delattre (1976), Ghazeli (1977), Boff-Dkhissi (1983) and El-Halees (1989), offered a cross section of the vocal tract in the sagittal plane. The pictures obtained, though not indicative enough as to the exact way the constriction in the pharyngeal cavity was achieved, did show the shape of the tongue in the oral and the pharyngeal cavities. Some of them, i.e., Ghazeli (1977) and Boff-Dkhissi (1983), could also show some degree of elevation of the larynx and the hyoid bone during the
production of lower pharyngeal consonants. When these findings are added to results obtained on the shape of the constriction from a top view of the tract, (such as our results reported in Chapter 2), a better picture can be drawn for the profile of the back cavity associated with pharyngeal articulation. Table 1.6 lists the physiological studies reported in the literature on the Arabic pharyngeal and pharyngealized articulation. The table shows the author name, publication year, number of speakers reported, the version of Arabic used by the speaker, the sounds examined and the technique used. The study reported by Sakai, Tanokuchi and Fujitaka (1995) in an abstract, did not mention the version of Arabic their speaker used. However upon inspecting the video film illustrating the experiment by the present author, we noticed that the speakers were three male Egyptians.

The studies by Marçais (1948), Abramson and Ferguson (1962), Ali and Daniloff (1972), Bonnot (1977), Giannini and Pettorino (1982) and Al-Ani (1970), provide X-ray pictures of the profile of the oral cavity to show the shape of the tongue during the production of the pharyngealized consonants as realized in the speech of speakers representing various Arabic dialects.

These studies showed only the upper part of the pharynx and the front cavity. All these studies showed that the pharyngealized consonants in Arabic have in common a depressed tongue blade and a retracted tongue root compared to their plain (non emphatic) counterpart, i.e., the oral dental consonants /t, d, s, z/.

Figure 1.7 shows an X-ray picture and a tracing for the same picture of the shape of the tongue in the vocal tract during the production of the pharyngealized consonant /d/ as produced by an Iraqi speaker, after Giannini and Pettorino (1982). In this figure it can be seen that the body of the tongue is depressed and its root is retracted causing a narrower pharyngeal cavity and larger oral cavity.

Lateral X-ray still-pictures (Ghazeli, 1977) showed that during the production of the true lower pharyngeal segments /ɬ, h/ the tongue-blade assumes a curved pyramidal shape (inverted “V”). Two points of constriction were observed, one at the hard palate located 6 centimeters from the lips while the other is located 3-4 centimeters above the glottis at the level of the epiglottis. The larynx was observed to ascend by approximately 9 mm relative to the rest position (Ghazeli, 1977). However, it is unexpected to be able to infer, from merely a lateral view, the exact mechanism by which the constriction in the lower portion of the pharynx is achieved. In Ghazeli’s study, the larynx and the hyoid bone were found to be raised during pharyngeal consonant production. Although the tracings reported show no velum lowering (p. 271), no explanation was provided as to the tongue shape which resembles an inverted “V”. If the only part of the tongue needed for creating the stricture in the lower pharynx is its root, it is expected that the tongue blade is as flat and depressed as during low back vowels. It should be noted that a similar shape was observed during swallowing (Donner, 1985) as well for all Arabic speakers reported in the studies used X-ray technique, e.g., Delattre (1971), Ghazeli (1977), Boff-Dkhissi (1983), Ghali, (1989) and Sakai et al. (1995).

If the velum is not pulled downward in Ghazeli’s data for the sole Tunisian Arabic speaker that participated in his experiment, why then were the larynx and the hyoid bone observed to be substantially raised upward? Ghazeli explained that the constriction in the lower pharynx is achieved mainly by the retraction of the root of the tongue and a slight inward displacement of the posterior pharyngeal wall. Figure 1.8 (after Ghazeli, 1977) shows the shape of the pharynx before the initiation of the /s/ movement and the shape of the vocal tract during the
articulation of the pharyngeal consonant /ŋ/ in /ææli/ and /h/ in the word /hææli/. It can be seen in that figure that the larynx is lifted upwards and from the constriction in the pharynx is not clear whether it is achieved by retracting the tongue root or by active contraction of pharyngeal muscles. It can also be seen that the jaw is opened during the production of these consonants which is a common feature of vowel production. Consonants are usually characterized by a closed jaw.

Figure 1.7. X-ray picture (top graph) and tracing for the same picture (bottom graph) during the production of the pharyngealized consonant /d̠/ as produced by an Iraqi speaker. After Giannini and Pettorino (1982).

It seems that these physiological data share in common the same pyramidal shape (inverted “V”) observed to be assumed by the tongue during pharyngeal consonant production. This observation supports the view, contrary to what is commonly believed, that the tongue alone can not be the main articulator for creating the constriction in the lower pharynx. The tongue, then, is expected to take an assimilated shape to the following or preceding vowel instead of that peculiar convex shape (see e.g., Figure 1.8). The view that pharyngeal articulation is attained solely by tongue root retraction also does not account for
the substantial raising of the larynx as well as the hyoid bone during pharyngeal consonant production.

Regarding the X-ray pictures published by Boff-Dkhissi (1983), see Figures 1.9 and 1.10 showing X-ray tracings of the shape of the vocal tract during the production of the pharyngeal consonant /ʢ/ in /aewae/, /h/ in /hæwæ/ and /ʢ/ in /yusʔɪnu/. The shape of the back cavity, as shown by lateral pictures, does not indicate any lowering of the velum during lower pharyngeal consonant production even in a nasal context (see Boff-Dkhissi, ibid., p. 329, Figure 41). However, it is unlikely that the traced pictures of Boff-Dkhissi reliably reflect the state of the velopharyngeal port during pharyngeal articulation as shown in Figure 1.10. The reason is that the pharyngeal consonant, if it presumably does not require an opened velopharyngeal port, occurs prior to a nasal consonant. It is expected that the velopharyngeal port will be opened to some degree at least because of the effect of the upcoming nasal consonant.

The pictures reported in the study of Al-Ani (1970) do not show any velum lowering during the lower pharyngeals either. However, the mandible is seen to be lowered to a large degree. The lower part of the pharynx is not shown in his pictures. Figure 1.11 shows tracings of the shape of the upper part of the vocal tract during the production of the pharyngeal consonants /ʢ/ in /aɛɛ/ and /h/ in /hæɛ/ as reported in Al-Ani (1970).

Figure 1.8. (A) The shape of the lower pharynx during the articulation of the pharyngeal consonant /ʢ/ in /aɛɛɛɛli/ (dotted line) and the shape of the pharynx before the initiation of the /ʢ/ movement (solid line). (B) The shape of the lower pharynx during the articulation of the pharyngeal consonant /ʢ/ in /aɛɛɛɛli/ (dotted line) and /h/ in the word /hæɛɛɛɛli/ (solid line). After Ghazeli (1977).

Delattre (1971) published tracings of the shape of the vocal tract during the production of various back consonants in Iraqi Arabic which do not show any velum lowering either, although it was mentioned in Hetzron (1969) that Delattre observed that one speaker of Arabic from Iraq showed a degree of velum lowering during the production of the voiced pharyngeal /ʢ/ similar to that during nasal consonants. However, this remark is not consistent with the tracing published in the later study reported by Delattre (1971). Figure 1.12 shows
tracings of the shape of the vocal tract during the production of various Arabic back consonants as uttered by a Lebanese speaker as reported by Delattre (1971).

The only available image which shows a lowered velum during the production of the voiceless pharyngeal /h/ (see Figure 1.13), is that reported in the study by El-Halees (1989). Also Ghali (1989) published two X-ray pictures and two fiberscopic images of /ʕ/ and /h/ in which the epiglottis are seen bending downwards.

**Figure 1.9.** X-ray tracings of the shape of the vocal tract during the production of the pharyngeal consonants: (A) /ʕ/ in /ˈæxæ/. (B) /h/ in /hæxæ/. After Boff-Dkhissi (1983).

**Figure 1.10.** X-ray tracings of the shape of the vocal tract during the production of the pharyngeal consonants /ʕ/ in /yusˈlm/lu/. After Boff-Dkhissi (1983). Notice the closed velopharyngeal port even in the context of a nasal consonant.
Figure 1.11. Tracings of the shape of the upper part of the vocal tract during the production of the pharyngeal consonants /ʕ/ in /ʕe/ (solid line) and /h/ in /hæ/ (dotted line). After Al-Ani (1970).

Figure 1.13 shows a xeroradiogram made for an Iraqi Arabic speaker during the production of the pharyngeal /h/. It can be seen in that picture that the epiglottis makes a complete closure with the back wall of the pharynx. It can also be seen in the same figure that the velum is lowered and the epiglottis is bent downwards covering the top of the arytenoids. Moreover, the shape of the tongue blade and root is similar to that shown in the X-ray pictures of other studies mentioned above, which we believe, is the characteristic articulatory feature for pharyngeal consonants. The back of the tongue was observed by El-Halees to be additionally drawn backward 3 mm during emphatic /h̊/ and 11 mm during emphatic /ʕ̊/ relative to their non-emphatic cognates /ʕ/, /h/, respectively.

Ghalii (1989) investigated the shape of the pharynx during the production of the pharyngeal consonants /ʕ/, /h/ in Egyptian Arabic for one male speaker. He published two pictures obtained using a still X-rays imaging technique for each of these two consonants. The pictures show that the corniculate cartilages (the apexes of the artitenoyed cartilages) are 5 mm farther from the posterior pharyngeal wall for /h/ than for /ʕ/ and the distance between this top and the epiglottis is 3 mm for /ʕ/ compared to /h/. This indicates that the size of constriction for /h/ is smaller than that for /ʕ/ and that the mandible is maybe lower for /h/ that for /ʕ/. Moreover, the position of the hyoid bone is also different in each case, being higher for /h/ than for /ʕ/. With the rising of the hyoid bone, the whole of the laryngeal structure is also raised. The distance between the highest point of the hyoid and the lower mandible is 9 mm for /ʕ/ and 7 mm for /h/. During the production of these two consonants, he observed that the uvula lying very close to the extreme back of the tongue indicating that the velopharyngeal port is substantially opened (ibid, p. 39). Fiberscopic images produced by Ghalii showed a considerably narrower opening between the posterior wall of the pharynx and the top of the epiglottis during the production of /ʕ/ (ibid, p. 43).
Figure 1.12. Tracings of the shape of the vocal tract during the production of various Arabic back consonants as uttered by a Lebanese speaker. After Delattre (1972), (the dot under the letters h and R indicate the voiceless pharyngeal /h/ and /ʁ/ respectively).
Figure 1.13. A xeroradiogram made for an Iraqi Arabic speaker during the production of pharyngeal /h/. The epiglottis (E) makes a complete closure with the back wall of the pharynx (BW). H, Hyoid bone. After El-Halees (1985). (In the picture, the velum is seen to be in a lowered position).

In the study by Hess (1990) where she re-analyzed X-ray pictures obtained for two Syrians and one Tunisian speakers from other studies, it was shown that the Arabic pharyngeal consonants /γ/, /h/ and the emphatic consonants /s̪/ and /t̪/ are distinguished by a lowered tongue dorsum for the pharyngealized consonants while they share retraction of the tongue root at the level of the epiglottis and raising of the larynx. However, no conclusion was made by Hess as to the mechanism underlying the production of pharyngeal consonants. Another study which stands in support of the findings obtained from the experiment conducted by Elgendy (1987) is that of Sakai, Tanokuchi and Fujiwara (1995). In their study,
they used the same fiberoptic technique as that used in Elgendy’s study (1987) as well as a videofluoroscopy (X-ray motion pictures) for the same speakers uttering the same words in two different recording sessions. Their method is more powerful since it compared the shape of the back cavity from a top view with that from a lateral view. The data are collected from three male speakers of Egyptian Arabic. Their fiberoptic observations showed that the epiglottis leans on the top of the arytenoids in a similar way as that reported by Elgendy (1987). They found that the velopharyngeal port was partially opened for two of the three subjects during the voiced pharyngeal consonant and closed for all three subjects during the voiceless pharyngeal consonant. Their findings also stand in support to the finding by Elgendy (1987) regarding the state of the glottis associated with pharyngeal articulation. They proposed that the Arabic pharyngeal should be described phonetically as a laryngeal fricative since they also observed a constriction in the glottis itself. However, this point is discussed in length in Chapter 2.

One study investigated the tongue profile during vowel production in several languages including Arabic, i.e., Wood (1979). Wood, using an X-ray technique, studied the articulation of vowels in Egyptian Arabic. Figure 1.14 shows sets of tongue profiles for tense-lax pairs by an Egyptian male subject. There are four examples of each vowel, except for [i] where there are 8 examples. In Wood’s X-rays material, we can see that the tongue for the pharyngealized Egyptian low back vowel is more depressed and retracted than in the non-pharyngealized environment. We will use these findings to draw a more complete picture of the profile of the vocal tract together with our findings on the shape of the pharyngeal cavity and jaw movement which are reported on in Chapters 2 and 3.

1.11.2. Acoustic and perceptual studies on Arabic pharyngeals

Next to the physiological data presented in the previous section we will present now the other source providing data on pharyngeal articulation in Arabic. There are several studies which examined the acoustic and/or the perceptual correlates of pharyngeal consonant production, i.e., Al-Ani (1967; 1970), Elgendy (1982), Adamson (1983), Norlin (1983), May (1979; 1981), Alwan (1986) and Butcher and Ahmad (1989).

Al-Ani (1969; 1970) studied the acoustic properties of the pharyngeal consonants, among other consonants and vowels, in Iraqi Arabic using spectrographic analysis. This study dealt with all Arabic consonants and vowels in various contexts and provided values of the first three formant frequencies as well as the duration. His spectrograms showed that the voiced pharyngeal /ɣ/, which was described as fricative, is realized as a pharyngeal stop in some of the utterances examined.

Elgendy (1982), also using spectrographic analysis, examined the inventory of all consonants in Egyptian Arabic as a function of various vocalic contexts. His study showed that the voiced pharyngeal consonants are characterized by a drop of the fundamental frequency compared to those for vowels. He concluded, based on the spectral properties, that the pharyngeal consonants in Egyptian Arabic are approximants. Adamson (1983) studied the pharyngeal consonants in Sudanese Arabic using spectrographic measurements and also concluded that these consonants are approximants.

The study of May (1979; 1981) investigated the perception of fricative consonants in Egyptian Arabic. Her data included the pharyngeal consonants, the uvular consonants as well as some of the front consonants. She concluded that fricative consonants in general are perceived categorically and identified mainly by the first two resonance frequencies. Moreover, voicing and segment duration are also important acoustic cues for discriminating between various pharyngeal consonants.
Norlin’s study (1983) was based on converting the FFT spectra to their critical band spectra which were analyzed in terms of the spectral center of gravity and dispersion. The point of measurement was the midpoint (25 milliseconds window) of each fricative consonant found in Egyptian Arabic followed by each of the five long vowels /ii, ee, oo, uu, ææ/. This method could reveal that /ʃ/ is characterized by a weak intensity and has its center of gravity in the lower frequency region. The voiceless counterpart /h/ has its center of gravity in the center of the critical band spectrum, with a fairly steep slope in the lower ranges and a more gradual slope in the higher frequencies. Furthermore, the results suggest that the pharyngeals /ʃ/ and /h/ are approximants, rather than fricatives.

Alwan (1986) derived an acoustical model representing the voiced /ʃ/ and /h/ from data obtained by Klatt and Stevens (1969) on one speaker of Lebanese Arabic. She verified the generated synthetic stimuli representing various pharyngeal consonants by perceptual tests. By determining the values of the bandwidths of the formant frequencies of these consonants, it was concluded that variations of the formant bandwidth are indicative to the perception of pharyngeal consonants.

The study of Butcher and Ahmad (1987) dealt with the acoustic and aerodynamics of pharyngeal consonants of Iraqi speakers. The nasal and oral airflow were measured, using a pneumotachograph system, during the production of /ʃ/ and /h/ in various vocalic contexts and positions in the word. They concluded, based on the measurements obtained, that pharyngeal consonants in Iraqi Arabic are also approximants and are articulated in a region of the vocal tract where true fricatives are very difficult to produce.
The lack of constancy in defining pharyngeal articulation phonetically, motivated us to examine some aspects, not yet explored, of the acoustic signals associated with these consonants. We examined the interrelationship between the place of articulation, degree of jaw height and the bandwidth of the first three formants frequencies. This study is reported in Chapter 4.

1.11.3. The phonology of pharyngeal consonants in Arabic

The accounts provided so far in this chapter on the phonetic, i.e., articulatory and acoustic, properties of pharyngeal and laryngeal consonants, give rise to certain questions about how a phonological treatment of this class of speech sounds can be presented. One of the aspects of the phonological system of a language is that which deals with the arrangement of the string of phonemes and the inter-relationship among these constituents comprising morphemes. The available phonological systems describing Arabic entail a specific phonological role of laryngeal and pharyngeal consonants which tend to behave in a similar way. Furthermore, on the morophophonological level, we also find evidence to the natural classification of the Arabic consonants into two main subclasses, i.e., that of the front and back consonant groups. The definite article morpheme in Arabic {ʔæl-} has two allomorphs. If the initial consonant in the word to be adjoined to that morpheme is a back consonant, the allomorph is {ʔæl-}. If the word has a front consonant in the initial position, the /V/ is assimilated to that consonant. For example, the word /faems/ “sun” becomes /ʔæ[æ]ums/ while the word/qamar/ “moon” will be /ʔælqamar/. The front consonants in that respect are the set of consonants which have their place of articulation in the oral cavity, from the lips to the velum. The back consonants are those articulated in the pharyngeal and laryngeal cavities and are referred to as the “guttural” consonants.

McCarthy (1991; 1995) advocated the proposal of merging laryngeal, pharyngeal and uvular consonants in one natural class of speech sounds called “Gutturals”, known by the medieval Arabic grammarians as “hoof Al Halq” “the sounds of the throat”. There are a number of phenomena characterizing the effect of the Semitic “guttural” consonants on the other consonants in a given phonetic environment. One of these phenomena is the effect of a guttural consonant on the height of the vowel in its vicinity. Vowel’s first and second formants were observed to be approximated in the neighborhood of a pharyngeal consonant (Elgendy, 1982).

Another phenomenon regarding the effect of pharyngeal articulation on syllable structure is the preference of a guttural consonant to occupy syllable initial over final position in a word (Mousa, 1972; Mrayati, 1987). Lower pharyngeal consonants tend not to form consonant clusters with other pharyngeal consonants.

There are several examples where a low back vowel is inserted between two consonants when either of the consonants is a pharyngeal consonant. This is also referred to as delaying the articulation of /V/ following geminate consonants, which is attained by inserting a schwa before /V/ or the tendency to de-geminate a cluster, i.e., separating the pharyngeal consonant from the non-pharyngeal consonant by a vowel. In several Bedouin dialects in Arabia and Egypt, insertion of a low back vowel /a/ before a guttural consonant has been observed (Mitchell, 1960; Blanc, 1970; Al-Mozaini, 1981; De Jong, personal communication). This phenomenon is known as the “gahawa syndrome”. In a word containing a back consonant, i.e., pharyngeal or laryngeal, as in the word /gahwa/ “coffee”, a low vowel is inserted after that consonant. The insertion of a schwa before the voiced pharyngeal /V/ when preceded by a geminate consonant is referred to as articulatory delay of /V/ as observed in the Bedouin Arabic of the nomadic desert tribes living in Sinai – Egypt (De Jong, 1999). Articulation
delay of /ʕ/ also occurs in the Fayyumi dialect of Egyptian Arabic only after a voiced singleton consonant. In this dialect an intrusive schwa is inserted before /ʕ/ while an /i/ is inserted after a geminate consonant (De Jong, 1999).

These observations may indicate that the production of pharyngeal consonants is not mechanically as simple as in the case of vowel production. By inserting a vowel prior to the pharyngeal consonant, the transition to the consonant and from the vowel would ease the production of /ʕ/. On sound spectrograms, the formant structure of the voiced pharyngeal /ʕ/ shows a prolongation of the transition of the consonant to the vowel with a great deal of coarticulation merging both consonant and vowel together (Elgendy, 1982).

Why do the so-called “guttural” consonants have that effect on the phonetic environment? None of the previous studies could account for these phenomena, neither could they provide an explanation for that behavior of this class of speech sounds. As an attempt to answer these questions, we will elucidate later in this thesis, the role of temporal constraints in determining the overall trajectory of the jaw moving from one segment to the other through the constituents of a string of phonemes.

1.12. Scope of the present study

It appears from the above mentioned points that pharyngeal consonant production can be more complex than what it is commonly thought to be. There are several reasons to think that pharyngeal muscles may be involved actively in the production of pharyngeal consonants.

Several recent models emphasize the importance of considering dynamic articulatory gestures rather than the steady-state (canonical) form of the phonetic segment. A standard model of speech production must consider activities of all parts of the vocal tract from the glottis to the lips. Since the pharynx constitutes more than half of the vocal tract length, it is important to provide a better understanding of its physiological behavior during speech. Certainly, that would improve the efficiency of the most commonly accepted current models and would deepen our insight in the process of speech motor control. To dissolve the presumed complex articulatory gestures associated with the production of pharyngeal consonants into its basic components, it is necessary to determine which of these components have linguistic value.

The present study was designed in order to 1) investigate some aspects of the articulatory dynamics associated with the production of various speech sounds articulated in the back cavity of the vocal tract; 2) attempt to account for temporal organization controlling these activities in terms of the effect of the motion on the structure of the pharyngeal cavity; and 3) suggest an explanation for the peculiar mandibular behavior (i.e., Elgendy, 1985b) observed during the production of the back consonants.

In the following chapters we present the data collected from convergent sources to establish a lawful description of the underlying mechanism characterizing the production of pharyngeal consonants in Arabic. Our aim is to approach a better understanding of the role of the pharynx in speech production from a different perspective. That will enable us, we believe, to construct a more realistic dynamical model of pharyngeal articulation and to account for the nature of coarticulation in the pharynx which is more a cavity than a typical articulator. Furthermore, the present study aims at attempting to provide a more precise phonetic description and to shed more light on the nature of pharyngeal articulation in relation to the other articulators involved. In the next chapter we will deal with the dynamics of the pharyngeal cavity during the production of pharyngeal and laryngeal consonants using a fiberscopic technique.