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Pharyngeal Articulations

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in Linguistics

by

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ABSTRACT OF THE DISSERTATION

Pharyngeal Articulations

by

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Pharyngeal consonants, low back vowels, segments with secondary pharyngealization, and vowels with advanced or retracted tongue root positions all involve some constriction in the pharynx. But there is no consensus among phoneticians and phonologists about how to describe these actions and how to group these classes of sounds together and represent them in phonological terms. A cross-linguistic study has been undertaken in order to determine the basic gestures used in forming pharyngeal articulations, to give us an understanding of how they are organized in different languages, and to provide a basis for improved feature representation. Factor analysis of tongue and vocal tract shapes from x-rays is used to identify basic patterns of articulation in the pharynx. X-ray data was selected from languages which make extensive use of constrictions in the pharynx: Akan, Arabic, Ndut and !Xóõ. The three most important findings are 1) [-ATR] vowels are articulated in a different way from the emphatic vowels in Arabic. The former have a constriction at the pocket of the epiglottis while the

dorsum in the upper pharynx. 2) The pharyngeal component of emphatic coronals is not articulated in the same way as pharyngeal consonants in Arabic. The emphatic coronals show retraction of the dorsum above the pocket of the epiglottis while the pharyngeal consonants show constriction of the laryngopharynx. 3) The constrictions for pharyngeal consonants and [-ATR] vowels also differ. The pharyngeal consonants involve constriction in the laryngopharynx below the pocket of the epiglottis which is different from the constriction of [-ATR] vowels centered at the pocket of the epiglottis. A tripartite division of the pharynx was proposed to account for the phonological and articulatory contrasts in the languages investigated in this dissertation. The Pharyngeal node is divided into [upper pharynx], [radical], and [laryngopharynx] constriction locations. The term [upper pharynx] has been proposed for the representation of emphatic consonants. [-ATR] vowels displayed a constriction centered at the pocket of the epiglottis, for which we have proposed the category [radical]. The category [laryngopharynx] is proposed for pharyngeal consonants in Arabic and strident vowels in !Xóõ.

CHAPTER 1 INTRODUCTION

1.0 What are pharyngeal articulations?

Articulations in the pharynx have posed problems in terms of their description, classification and representation by features. The segments which have a constriction in the pharynx include the primary pharyngeal consonants found in some Semitic and Caucasian languages; "deep" pharyngeals found in some Caucasian languages like Agul, the emphatic (pharyngealized or velarized) consonants also found in Semitic; the retracted tongue root ([-ATR]) vowels found in many Niger-Kordofanian and Nilo-Saharan languages; the pharyngealized vowels found contrastively in Khoisan languages and allophonically in Semitic; and finally, a somewhat more common class, low back vowels.

In proposing features, we want to characterize natural classes and express generalizations about what classes occur in phonological rules. Many of these natural classes are based on articulatory similarity, and thus we need to be able to determine which segments are similar articulatorily. All of the segments discussed in this dissertation have constrictions in the pharynx, but they are not consistently grouped by linguists in any one way. Thus, different phonological proposals differ on how similar the segments in question are considered to be. In order to judge articulatory similarity, we need to know if any of the above segments are produced in the same place and in substantially the same way. This dissertation presents a cross-linguistic study undertaken in order to determine the basic gestures used in forming pharyngeal articulations, to give us an understanding of how they are organized in different languages, and to provide a basis for improved feature representation. Factor analysis of tongue and vocal tract shapes from x-rays is used to identify basic patterns of articulation in the pharynx. X-ray data was selected from languages which make extensive use of constrictions in the pharynx: Akan, Arabic, Ndut and !Xóõ.

In this chapter we will first discuss some of the phonological feature systems which have been used to classify pharyngeal and pharyngealized segments and secondly, what is known about the articulatory positions of these segments. Uvular segments will be discussed briefly but are not the focus of this study.

1.1 Phonological classification and feature assignment

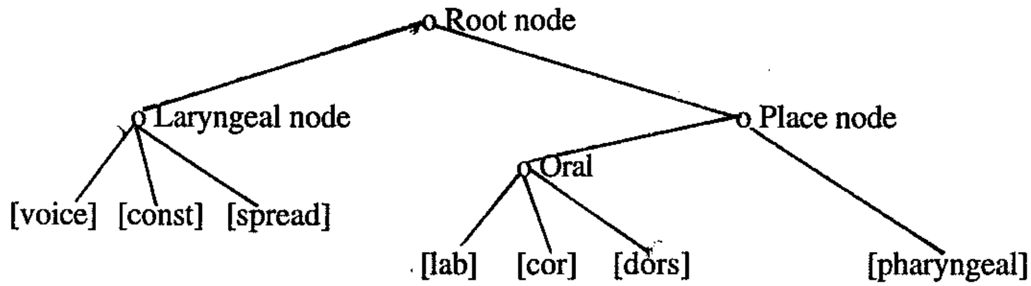
There have been many different proposals for classifying these segments and assigning features to them, four of which we will review here. Earlier proposals will be discussed in terms of their similarity to these four recent approaches. Like most current phonological models (Clements, 1985, Sagey, 1986, Archangeli & Pulleyblank, 1992, McCarthy, 1994, Ladefoged, 1994, among others), the four to be discussed here utilize hierarchical feature representation as a means of constraining permissible feature combinations and to better characterize natural classes of sounds. Some are articulator-based and some are based on place of articulation, or a combination of the two. Our goal here is to introduce the sorts of features that may be used to represent pharyngeal articulations and the facts and patterns which must be taken into consideration.

To start with familiar ground, *The Sound Pattern of English* (SPE) (Chomsky & Halle, 1968), gave the same features to low vowels and pharyngeals, [+low, -high], and a different feature to [±ATR] vowels, [±covered]. One criticism of SPE was that it could not provide a way to distinguish place differences in the pharynx, as is necessary for some Caucasian languages and for the two kinds of pharyngealized vowels in !Xóõ.

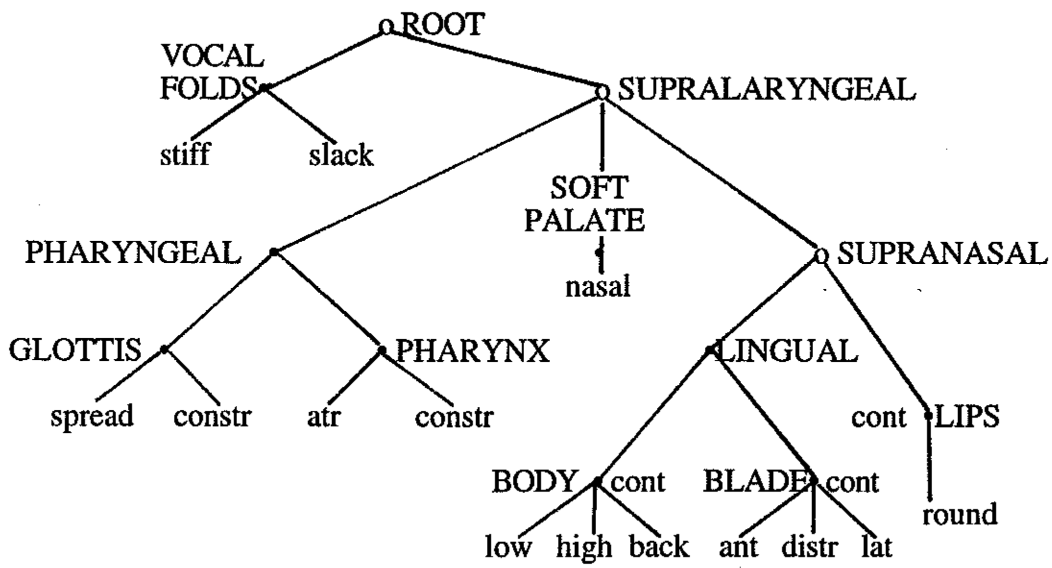
Ladefoged & Maddieson (1996) set up a classificatory system for articulations based on the five major parts of the vocal tract that move: the lips (Labial), the tip and blade of the tongue (Coronal), the body of the tongue (Dorsal), the root of the tongue and the epiglottis (Radical), and the glottis (Glottal). These five independent active articulators are seen as establishing a set of major place features, under which are grouped individual places of articulation. In the Radical region, they recognize two places: Pharyngeal and Epiglottal. Two places enable Ladefoged & Maddieson to distinguish pharyngeal and epiglottal fricatives in the Burkikhan dialect of Agul. This classification for consonants is not extended to vowels, which have their own parameters: [+ATR] and [-ATR] (Pharyngealized). Ladefoged & Maddieson were unable to decide on suitable phonological parameters to describe the three-way distinction between plain, pharyngealized and strident vowels in !Xóõ. None of the other proposals discussed below discuss the !Xóõ problem.

Below, we will contrast the approach by Ladefoged & Maddieson (1996), in which the Radical articulator is defined in the same way as other articulators, and those by McCarthy (1994) (1-1), Keyser & Stevens (1994) (1-2) and Halle (1989) (1-3), in which pharyngeal articulations are given a different status from other articulations in the vocal tract. We will not discuss each proposal in detail; (1-1)-(1-3) list feature hierarchies for each proposal as reference. The latter three proposals are noteworthy in that they devote special attention to the representation of pharyngeal articulations.

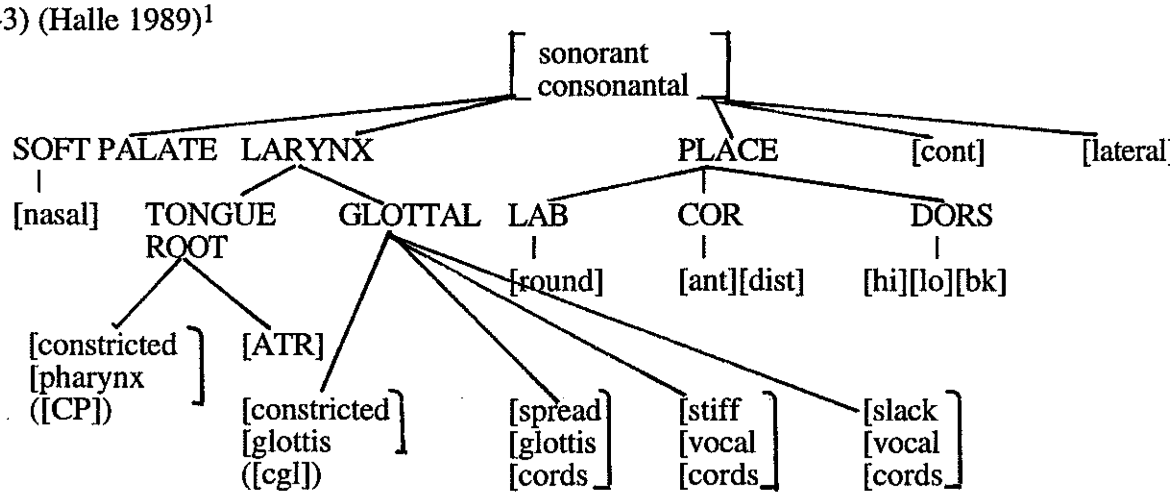
(1-1) McCarthy (1994)



(1-2) Keyser & Stevens (1994)



(1-3) (Halle 1989)[1]



[1]This feature tree is constructed from partial trees in the article and does not appear in its entirety there.

Halle (1989), Keyser & Stevens (1994) and McCarthy (1994) all utilize hierarchical feature representation and all have redefined the node dominating pharyngeal articulations so that it is no longer on a par with the other place features (labial, coronal and dorsal). McCarthy leaves [pharyngeal] under the place node, but separate from other Oral articulators, and defines it as a place of articulation rather than an active articulator. Halle and Keyser & Stevens remove it from under the place node and combine it with gestures involving the larynx. Below we will list some of the reasons given for the different status of pharyngeal articulations:

1) All segments produced in the pharyngeal-laryngeal area are [-consonantal] (Halle, Keyser & Stevens) or approximants (McCarthy).

2) Segments dominated by the supralaryngeal node, i.e. oral and nasal glides, laryngeals and pharyngeals, have relatively slow changes in the frequencies of the spectral peaks, and "spectral changes are in the vicinity of a region with a minimum amplitude" (Keyser & Stevens, 1994:216).

3) The gutturals (χ, ʁ, ħ, ʕ, h, ʔ) have a relatively high F_1, theoretical in the case of [h, ʔ] as it is not excited by a source (McCarthy).

4) Anatomically, pharyngeals and laryngeals are below the velopharyngeal port and thus cannot be nasalized; they also do not depend on the mandible in any way for implementation unlike sounds in the anterior part of the vocal tract (Keyser & Stevens); the gutturals in Semitic which are argued to form a phonological class are all produced in the posterior region of the vocal tract (McCarthy).

5) The pharynx has fewer sensory endings than the anterior vocal tract and articulations are thus made with less precision (McCarthy, Keyser & Stevens).

It should be noted that the hierarchical structures of both Halle and Keyser & Stevens depend crucially on the assumption that all sounds produced in the pharynx are

[-consonantal], while McCarthy's structure requires the class of gutturals to be defined as approximants. The difficulty with these definitions is that pharyngeals can be fricatives, as in the Tunisian Arabic [ħ] which exhibits strong non-periodic noise (Ghazeli 1977:45), or stops, as in the Agul deep pharyngeal stop [ʡ] (Catford 1983:347) or the epiglottal stop in Dahalo (Maddieson, Spajic, Sands & Ladefoged 1993). Uvular stops and fricatives are even more widely attested. Hence it is not clear that all of the sounds with these places can be satisfactorily analyzed as [-consonantal] or as approximants. This issue is discussed in more detail in §1.2.1.

Each of the classifications above makes physical claims about which segments are similar articulatorily. Ladefoged & Maddieson (1996) provide for two places of articulation in the pharynx while the other three proposals only provide for one place of articulation in the pharynx (McCarthy: [pharyngeal], Keyser & Stevens: [PHARYNX], Halle: [TONGUE ROOT]). The actual location is not specified in these three proposals. Even proposals which group uvular and laryngeal segments together with pharyngeal segments are only providing for one type of true pharyngeal segment created by an oral constriction in the pharynx.

McCarthy, Keyser & Stevens, and Halle all group laryngeal segments with pharyngeal segments in some way. McCarthy (1994) does not discuss how they would be distinguished, although presumably it is by presence or lack of a pharyngeal constriction. Both Keyser & Stevens and Halle provide a branching node (PHARYNGEAL/LARYNX respectively) under which there is one branch for pharyngeal segments (PHARYNX/TONGUE ROOT respectively) and another for laryngeal segments (GLOTTIS/GLOTTAL respectively). Halle made the TONGUE ROOT subordinate to the LARYNX node because the muscles of the larynx control positioning of the epiglottis and other structures of the upper end of the larynx. This is not strictly true, as there is evidence that control of the tongue root and of the larynx is more independent than Halle has assumed. In support of his proposal that the Tongue Root and Glottal articulators are dominated by the Larynx node, Halle says " a modicum of support . . . is provided by the fact that in many languages the Tongue Root features - both [Constricted Pharynx] and [ATR] - induce noticeable modifications in voice quality" (Halle 1989:18). Keyser & Stevens want to recognize that these connections may be utilized in some cases; but they state that "it appears that the pharyngeal and laryngeal adjustments can also be performed independently, since changes in laryngeal state do not always accompany pharyngeal expansion and contraction" (Keyser & Stevens 1994:213). In §1.2.5.3, we will discuss cases where tongue root advancement is not accompanied by breathy voice (Akan) and where breathy voice is not accompanied by tongue root advancement (Nyah Kur). Ladefoged & Maddieson (1996) separate pharyngeal articulations from glottal ones; Trigo (1991) also concludes that pharyngeal and laryngeal features must be independent.

For Halle and Keyser & Stevens, [ATR] is a separate feature from [constricted (pharynx)]. Ladefoged & Maddieson label their features [ATR] and [-ATR] (pharyngealized), which appears to imply more of a similarity between [-ATR] vowels and pharyngealized vowels than Halle and Keyser & Stevens. McCarthy (1994) does not address [ATR].

There is a lack of consensus on whether low vowels are presumed to share features with pharyngeal consonants or not, and which features are assigned in common. SPE assigns dorsal features, also used for vowels, to pharyngeal consonants, whereas McCarthy assigns [pharyngeal] place to low vowels, and Ladefoged & Maddieson (1996) have separate features for consonants and vowels. Ultimately a decision to use vowel features for consonants or consonant features for vowels or the same set for both consonants and vowels must rest on evidence from the phonologies of natural languages, in addition to evidence of their articulatory similarity.

In the following sections, we will discuss what is known about the articulation of pharyngeal segments.

1.2.0 Phonetic descriptions of pharyngeal articulations

1.2.1 Primary pharyngeal articulations

As has often been remarked, pharyngeal articulations are comparatively rare. In the genetically-balanced language survey in Maddieson (1984), only twelve languages (3.8%) are listed as having pharyngeal consonants. The newly expanded version of Maddieson's data-base lists nineteen languages.[2] However, although these consonants are rare, they appear in diverse language families: Afro-Asiatic, Indo-European, Niger-Kordofanian, Nilo-Saharan, Austro-Tai, Amerindian, and Caucasian.

The majority of the data discussed below is from Arabic and a smaller amount is from Caucasian languages. There is no articulatory data on Northwest Amerindian languages, though acoustic data can be used to hypothesize on the location of the constriction. Bessell (1991) provides acoustic data on vowels adjacent to uvulars and pharyngeals in the Interior Salish language Nxaʔamxčin, but no direct measurements of the consonants themselves. Her data will be discussed in section §1.2.4. Flemming, et al. (1994) discuss acoustic effects of pharyngeals on neighboring segments in Montana Salish.

The first question we need to address is: What is the active articulator(s) for pharyngeal consonants? Some phoneticians define a pharyngeal articulation purely in terms of tongue root movement. For instance, Delattre (1971:129) says "a pharyngeal

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[2]Arabic, Iraqw, Shilha, Somali, Tigre, Kurdish, Ewe, Tama, Atayal, Nootka (Tseshaht), Kabardian, Lak; Brao, Rutul, Bats, Archi, Avar, Socotri, Dahalo.

articulation is one in which the root of the tongue assumes the shape of a bulge and is drawn back toward the vertical back wall of the pharynx to form a stricture." Ladefoged (1993:163) gives a similar definition: "pharyngeal sounds are produced by pulling the root of the tongue back toward the wall of the pharynx." Catford (1977:163) labels this type of pharyngeal "linguo-pharyngeal", and suggests that this is the articulation of the Danish 'pharyngeal r' and of the pharyngealized component in pharyngealization.

Catford makes a distinction between linguo-pharyngeals and faucal or transverse pharyngeals. The latter is a "sphincteric semi-closure created by a lateral compression of the part of the pharynx immediately behind the mouth, so that the faucal pillars move towards each other" (Catford 1977:163). This is said by Catford to be the most common articulation of the pharyngeal approximants [ħ] and [ʕ] in Avar (Catford 1983:346).

Other phoneticians mention the epiglottis in the production of pharyngeal consonants. Ladefoged & Maddieson (1996:169) cite evidence on Arabic dialects showing that pharyngeal articulations in Arabic are formed in the epiglottal region using both the epiglottis and the root of the tongue. They "suggest that these Semitic fricatives might more properly be called epiglottal rather than pharyngeal" (Ladefoged & Maddieson 1996:168). While Ladefoged & Maddieson agree with Boff Dkhissi (1983) that the epiglottis and the root of the tongue work together in forming the constriction, other linguists have suggested that the epiglottis works independently. Laufer & Condax (1979:51) believed that the epiglottis acted as an independent articulator in the formation of pharyngeals in Hebrew. However, Laufer & Baer (1988:198) say that their new data on both Hebrew and Arabic do not support that claim. In the later study, they found that both the epiglottis and the tongue root were retracted, so it was not clear if the epiglottis was playing an independent role as was previously claimed. In his fiberscopic study of nine Egyptian speakers, Elgendy (1992:1297) stated that the epiglottis moved independently of the tongue; however, he also says that "the epiglottis leans on the top of the arytenoid cartilages", which were themselves raised and fronted. This indicates that the larynx is involved in a laryngopharyngeal closure and the tongue root and epiglottis are pressing down as well as back. This would allow the tip of the epiglottis to travel further back than the tongue root, but it does not mean that the two movements are independent.

Ghazeli (1977:36-7) found the pharyngeal consonants in Tunisian Arabic to be formed by a combination of movements: a backward movement of the root of the tongue, a forward displacement of the lower end of the back wall of the pharynx, and elevation of structures at the base of the pharyngeal cavity (i.e., the larynx, the periarytenoid fold which separates the larynx from the esophagus, and the esophagus vestibule). New tracings of /ħ/ and /ʕ/ from Ghazeli's film appear in (1-4). The laryngopharyngeal narrowing in Ghazeli's pharyngeals would appear to be similar to that described by Elgendy (1992), but it remains to be seen if this combination is characteristic of Arabic as a whole.

There are three sources of x-ray data on consonants in Caucasian languages: Bgažba (1964) on Bzyb, Leroy & Paris (1974) on Ubykh, and Gaprindašvili (1966b) on Dargi. The first two sources have been extensively discussed by Colarusso (1975), who also provides acoustic data. The x-ray 'tracings' of Leroy & Paris do not seem to be tracings but are perhaps sketches, and it is difficult to use them with any confidence. Those by Bgažba are of better quality, but represent only a scattering of segments from several speakers. Unfortunately, he does not include pharyngeals, but he does include two uvulars and two pharyngealized uvulars. The latter are characterized by a greater narrowing in the upper pharynx below the tip of the uvula than the plain counterparts while the root of the tongue presses against the tip of the epiglottis. These might be similar to Arabic emphatics but more data is needed.

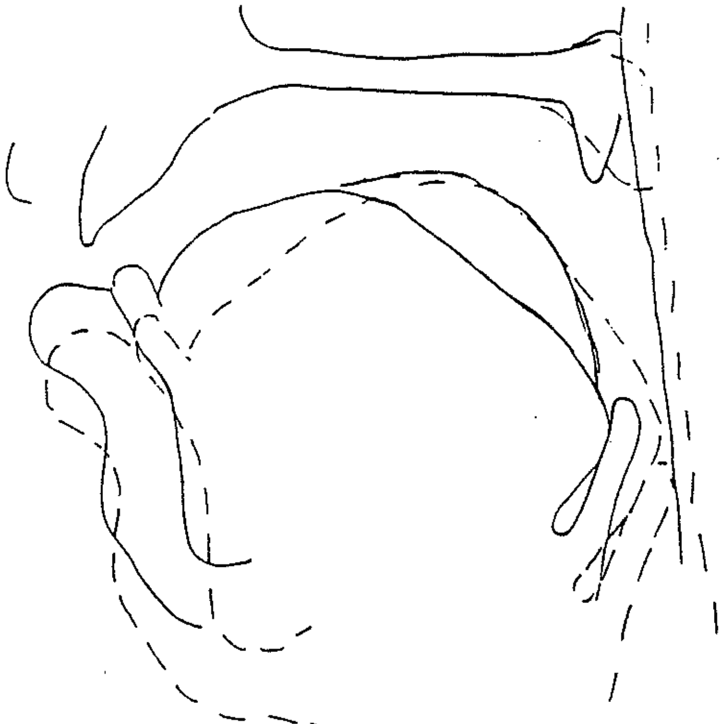
Gaprindašvili (1966b) presents a greater quantity of data: x-ray tracings, palatograms and some airflow and oscillogram tracings of various sounds from two dialects, Khaydak and Kebakh-Mulebkin, of Dargi (a Dagestanian language). These appeared to be of reasonable quality. However, it was found that the tracings are not all of the same scale, and in some cases are distorted along the horizontal axis, rendering them unsuitable for measurement purposes. We will briefly describe the three tracings of two mid-pharyngeal spirants, as they show two different pharyngeal articulations. One tracing of each type of articulation is superimposed in (1-6). There are two tracings of the first articulation in Gaprindašvili (Ibid.) (Figures 59 and 62; Fig 62 is reproduced in (1-6)), one voiceless from one dialect and one voiced from the other. Both show the tongue root to be pushed down as well as back while the front of the tongue is raised, creating a mid-sagittal valley in the rear dorsum. Gaprindašvili (Ibid.:80) says the "upper part of the larynx is closely pressed to the root of the tongue and they together articulate against the back wall of the pharynx."[3] It is a lower articulation than that found in the Arabic pharyngeals of Ghazeli (1977).

The second question we will address is: What is the place(s) of articulation for consonants articulated in the pharynx? Actual place of constriction in the formation of primary pharyngeal consonants is often not mentioned except in detailed x-ray studies, or when describing cases of contrast, as in !Xóõ and some Caucasian languages. X-ray studies of Arabic (Ghazeli, 1977:37; Laufer and Baer, 1988:190) indicate that the main constriction is generally at the level of the epiglottis. There is some question as to whether the main constriction is between the epiglottis and the rear wall of the pharynx,

[3]Translated by Evelina Parsch (p.c.).

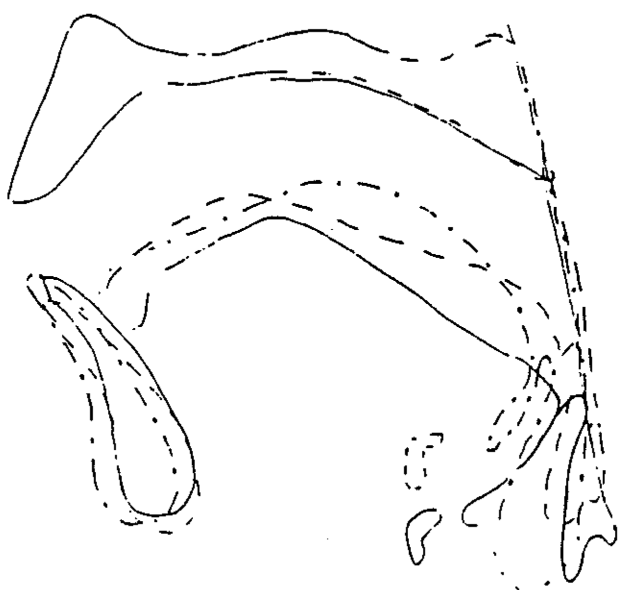
or between the epiglottis and arytenoid cartilages + ventricular bands. A number of researchers have described the pharyngeal consonants in Arabic as involving a constriction between the epiglottis and upper laryngeal structures. The earliest description I have found was given by Gairdner (1925:27) without the benefit of physiological data: "It is probable in forming it [/ħ/] the epiglottis descends, leaving only a narrow passage past the 'false vocal cords', through which the air is forced." Al-Ani (1970:60) in a footnote on /ħ/ says "It is possible, as suggested by Dr. Shoup, that a constriction is also formed by the false vocal cords." El-Halees (1985:288) found in his fiberoptic study of Iraqi Arabic that during the production of pharyngeals the epiglottis was so far back and so low that it covered the laryngeal vestibule and created a very narrow stricture with the back wall of the pharynx.

Another view would be that the production of pharyngeal consonants involves both a constriction against the back wall of the pharynx and one between the base of the epiglottis and upper structures of the larynx in varying degrees. Ghazeli (1977:49) believes that constriction of the pharynx results in a constriction of the larynx, and results in the somewhat creaky voice noticeable in /ʕ/. Ghazeli also thinks that the friction during /ħ/ is created by intra-laryngeal adjustments as in some cases the constriction in the pharyngeal cavity would have been too wide to produce the audible frication. Laufer & Condax (1979:51) also found cases where the opening between the epiglottis and the dorsal pharyngeal wall was too wide to be the source of the friction and postulated that "the friction results from air passing through the constriction between the base of the epiglottis and the arytenoids." In such cases, it would be difficult to argue that the constriction of the pharynx caused the constriction in the larynx.



(1-6) Enlarged and superimposed tracings of two varieties of [ʕ] in Dargi from Gaprindašvili (1966b).

_______ [ʕ] in Figure 62 ------- [ʕ] in Figure 63



(1-7) New tracings of plain [a], pharyngealized [a̰] and strident [a̰h] in !Xóõ, speaker G, from film by Traill.

_·_·_ [a] in [dt'kx'qala] -------[a̰] in [na̰a] _______ [a̰h] in [ʔa̰hna]

Several researchers have found a somewhat more systematic, although non-contrastive, difference in the location of pharyngeal constrictions in Arabic. Delattre (1971:134) notes, through examination of x-rays, that place of constriction varies for voiced and voiceless pharyngeal consonants in Lebanese Arabic. He found that the pharyngeal stricture for /ħ/ was lower than that for /ʕ/, and that /ħ/ had a slightly higher first formant. Enlarged and superimposed tracings of /ħ/ and /ʕ/ in Lebanese Arabic, after Delattre (1971), are shown in (1-5). Looking at his x-ray tracings, it would appear that the narrowest constriction is between the epiglottis and the pharyngeal wall. He does not trace the upper structures of the larynx, so there is no way of knowing whether the lower articulation for /ħ/ was due to an epiglotto-arytenoidal constriction made in order to produce more fricative noise. El-Halees (1985:288) also found that the constriction for /ħ/ was lower and narrower than the constriction for /ʕ/ in Iraqi Arabic, but does not supply fiberoptic pictures to illustrate the difference. He did find that listeners were more likely to hear a sound as /ʕ/ than as /ʁ/ at a lower F_1 frequency than for the pair /ħ/ and /χ/, and suggests that this is due to the lower constriction location of /ħ/.

The location of the constriction is naturally of primary importance in determining the acoustic characteristics of the articulation. In Arabic, most researchers (see for instance Delattre, 1971; Ghazeli, 1977; El-Halees, 1985; Butcher & Ahmad, 1987) note that the pharyngeal consonants are characterized by a high first formant. Two perceptual studies, by El-Halees (1985) and Alwan (1987), found that the value of the first formant was used by listeners to discriminate between pharyngeal and uvular stimuli. Delattre (1971) and Ghazeli (1977) also note that the second formant is lowered in pharyngeals due to the large mouth cavity.

In Arabic pharyngeals, there appears to be a secondary narrowing in the anterior vocal tract. Both Delattre and Ghazeli note that the front of the tongue is raised during the production of /ħ/ and /ʕ/. See (1-5) and (1-14).) Delattre (1971:134) says that the front of the tongue dorsum for /ħ/ and /ʕ/ is higher and more fronted than for /a/. Ghazeli says "another narrowing of the vocal tract takes place about six cm. from the lips, resulting in the shape of the tongue being similar to that of a pyramid..." (1977:37). Delattre (1971:134) also found that the back of the tongue is cambered in /ħ/, "as if the radical bulge toward the lower pharynx forced a compensatory hollow above it." As a result of this movement, the cavity under the palate is much smaller, and a large cavity is formed under the soft palate and in the upper pharynx, similar to American /r/. Delattre (1971:135) found a lowered F_3 in both Arabic pharyngeal consonants, similar to but less extreme than that in American /r/. Gaprindašvili also shows one x-ray tracing (Gaprindašvili Fig.63, also reproduced in (1-6)) of a variant of the voiceless mid-pharyngeal spirant in Dargi where the mid-dorsum rather than the front dorsum is raised. In consequence, there is no mid-sagittal valley, and the articulation looks remarkably similar to Ghazeli's pyramid-shaped pharyngeals in Arabic.

This raising of the tongue can perhaps be interpreted as a front tongue position at least in Arabic, as suggested by McCarthy for a separate reason: McCarthy says that "the tongue body is not back but front in Arabic pharyngeals, as we can see by the adjacent front allophone of the low vowel: compare pharyngeal [ħææl] "condition" with uvular [χɑɑl] "maternal uncle."" (McCarthy 1994:197) We will return to this question in §1.2.6.

The third question we will discuss here concerns the manner of articulation of pharyngeal consonants. Recent phonological proposals classify all pharyngeal segments as approximants (McCarthy, 1994) or as [-consonantal] (Keyser & Stevens, 1994;

Halle, 1989), which would place them in the same class as semivowels ([j, w]) and liquid approximants ([l, r]) for the first category, and additionally with vowels in the second. Catford's definition of approximant is invoked by McCarthy in support of his classification: "approximants ... have non-turbulent flow when voiced; but the flow becomes turbulent when they are made voiceless..." (Catford, 1977:122). This definition assumes the same constriction for voiced and voiceless segments, which may not be the case for /ħ/ and /ʕ/. Along with El-Halees (as mentioned above), Ghazeli (1977:37) says that the "constriction between the epiglottis and the back wall of the pharynx is generally narrower for /ħ/ than for /ʕ/ (3 mm and 4 mm, respectively)." Catford states that the cross-sectional area of the articulatory channel of approximants ranges from about 20 mm^2 to around 80-100 mm^2; 20 mm^2 is the region of changeover from fricative to approximant (Ibid:122, 121). Yeou & Maeda (1995), based on x-rays of Tunisian Arabic from Ghazeli (1977), calculate that the area of constriction appropriate for modeling /χ, ʁ, ħ, ʕ/ is in the order of 0.20-0.35 cm^2. The area of these channels, then, is just at the changeover point from fricative to approximant.

In descriptions of Arabic pharyngeals, /ħ/ is usually described as a fricative (Al-Ani, 1970:60; Ghazeli, 1977:45; Adamson, 1981:93), while descriptions of /ʕ/ range from an approximant to a fricative to a stop. For instance regarding /ħ/, Ghazeli (1977:45) states it "is acoustically characterized by strong non-periodic noise but with visible formant structure." Al-Ani (1970:62) found the most common allophone of /ʕ/ to be a voiceless stop in data from Iraqi Arabic speakers. Ghazeli (1977:43) says that it is a fricative both in his speech and that of his Iraqi speaker. However, there is very little non-periodic noise visible in his spectrograms of /ʕ/ except in word-initial position. He also noted that the vocal cords vibrated at a slower rate for /ʕ/ than for adjacent vowels and that /ʕ/ was sometimes accompanied by creaky voice. El-Halees (1988:288) found stops in initial position in Iraqi Arabic. Adamson (1981:87) found speaker-specific differences in the production of /ʕ/ by four speakers of Sudanese Arabic. Two tended to produce an approximant in most situations, but also occasionally produced them with creaky voice. The other two tended to use creaky-voice or stop articulations more frequently. The stops were sometimes followed by a brief period of creaky voice. Ghazeli (1977:49) believes that "the constriction of the pharynx during the production of pharyngeals also results in a constriction of the larynx. This results in the somewhat creaky voice noticeable during the articulation of the voiced pharyngeal /ʕ/." One could speculate that both the creaky voice and the stops are made through constriction of the larynx caused by compression against the epiglottis, the stops resulting from complete closure between the epiglottis and upper laryngeal structures. As for /ħ/, Ghazeli (1977:49) says that "it seems to me that the friction during /ħ/ is created by intralaryngeal adjustments rather than the relatively wide constriction between the epiglottis and the pharyngeal wall." Maddieson (p.c., 1998) suggests that "it's also possible that an acoustic effect similar to creaky voice is produced by trilling of the epiglottis" and that such a phenomenon may occur in Amis. This would require a fairly narrow aperture between the tip of the epiglottis and the pharyngeal wall and rather precise airflow to yield a creaky effect, but would not necessarily require constriction of the epiglottis against the upper laryngeal structures as posited by Ghazeli.

We find then, that there is allophonic variation and speaker variation in the production of /ħ/ and /ʕ/ in Arabic. /ʕ/ may appear as a stop or a fricative in initial position but as an approximant inter-vocalically. This pattern of positional variation is also characteristic of other non-strident fricatives such as [v, ð] in English (P. Keating, p.c.). Creakiness in /ʕ/ appears to be speaker-specific. There may be constriction of the larynx in the production of /ħ/ and /ʕ/ in Arabic.

While the classification of Arabic pharyngeal consonants as approximants has not been resolved, there are data on pharyngeal fricatives and stops in other languages clearly demonstrating that they are not approximants. Spectrograms of Agul pharyngeal and epiglottal fricatives are given in Ladefoged & Maddieson (1996:168). Pharyngeal stops are attested in Dahalo and Agul. Dahalo, a Cushitic language of Kenya, has a rich consonant inventory which includes ejectives, implosives, clicks and two pharyngeal segments. Maddieson et.al. 1993 classify /ʡ/ as a voiceless epiglottal stop and /ʜ/ as a voiceless epiglottal fricative in utterance-initial position or when appearing as a geminate in intervocalic position. Of interest to the debate on whether pharyngeals should be given the features of approximants, Maddieson et al. (1993:30) say that "the most typical pronunciation of the segment we write /ʡ/ is as a stop." However, like many obstruents in the language, both segments undergo laxing and may be partially voiced, /ʡ/ appearing as an epiglottal tap or as an approximant and /ʜ/ as a voiced approximant.

This survey raises a number of questions about primary pharyngeal articulations. First, we are interested in how the constriction is accomplished, whether by the tongue root, epiglottis, sphincteric contraction of the pharynx, or some combination of these. In addition, we wish to investigate whether certain languages consistently press the tongue root down against the larynx and/or raise the larynx in making pharyngeal consonants. In addition, we need to examine the configuration of the rest of the tongue during pharyngeal consonants: does the front or mid dorsum tend to be raised and is there sulcalization of the tongue? Second, we are curious as to how many constriction locations need to be defined and where they are located: one (*SPE*, Halle, Keyser & Stevens), two (Ladefoged & Maddieson) or possibly more. Ladefoged & Maddieson

(1996:169) suggest that there may be a range of possible gestures rather than two distinct regions. A further issue, which is perhaps not best resolved from x-ray data, is the classification of pharyngeal consonants by stricture type. This issue is important for the set of phonological features assigned to pharyngeal articulations and to the organization of feature hierarchies.

1.2.2 Deep Pharyngeals

"Deep" pharyngeals, i.e. those made closer to the glottis than the pharyngeals mentioned above, are even rarer. The only mentions of which I am aware are in Caucasian languages such as Agul, and in the Southern Khoisan language !Xóõ. The Burkikhan dialect of Agul has seven pharyngeal and laryngeal sounds: pharyngeal /ħ/ and /ʕ/, "deep" pharyngeal /ʜ/ /ʢ/ and stop /ʡ/, and glottal /h/ and /ʔ/ (Catford 1983:347). Ladefoged & Maddieson (1996:168) provide examples of contrast between the pharyngeal and epiglottal (or deep pharyngeal) fricatives in this dialect. While there are no minimal pairs, there are several examples which show very similar environments. Catford (Ibid:347) suggests that /ʢ/ in Agul may be an epiglottal trill, since "a low frequency vibration can often be observed, which is possibly due to epiglottal vibration." Catford says the stop /ʡ/ which occurs in Chechen has been described as a "pharyngeal stop" or as a "glottal + ventricular stop + pharyngeal constriction (Catford Ibid.:346), but suggests on the basis of Laufer & Condax (1979) that it is an epiglotto-arytenoidal constriction (Catford 1983: 347). The stops in Dahalo mentioned above, are also thought to be epiglottal.

We will discuss the strident vowels in the Khoisan language !Xóõ here, rather than in the section on pharyngealized vowels, in order to facilitate comparison with 'deep' pharyngeals in Caucasian languages. !Xóõ has two kinds of pharyngealization on vowels, one more extreme than the other. (See (1-7).) Traill (1985:78) calls the vowels which exhibit extreme pharyngealization “strident vowels”. In the strident vowels /a̰h, ṵh/, the body of the tongue is even lower than it is for the other type of pharyngealized vowels. The cushion of the epiglottis is compressed towards the arytenoid cartilages, the arytenoid cartilages vibrate vigorously, and the tip of the epiglottis vibrates against the back wall of the pharynx (Ibid.:78). Traill suggests that the vibration of the arytenoid cartilages is imparted to the epiglottis; another possibility is that the narrow constriction causes the epiglottis to vibrate. Spectrograms published in Ladefoged & Maddieson (1996:312) support this description. The formant structures of these vowels display raised first and second formants and a lowered third formant.

It thus appears that the place and manner of articulation of the deep pharyngeals in Caucasian languages and of the strident vowels in !Xóõ are similar. Both seem to involve extreme retraction of the tongue root, and the formation of a epiglotto-arytenoidal constriction, which may lead to epiglottal trilling. In the previous section, we found descriptions of the Arabic pharyngeals to vary between retraction of the tongue root at the level of the epiglottis, and compression of the epiglottis against the upper structures of the larynx. The latter case sounds like the deep pharyngeals discussed in this section and we are interested in whether the Arabic pharyngeals are similar to 'deep' pharyngeals or not.

1.2.3 Secondary Pharyngeal Articulation: Pharyngealization on consonants

Pharyngealization is generally described as a superimposition of a narrowing of the pharynx (Ladefoged, 1993:231). Pharyngealized consonants are even rarer than primary pharyngeal consonants: Maddieson (1984) lists just three Afro-Asiatic languages (less than 1% of the data-base) and the expanded data-base only adds two Caucasian languages.[4] The pharyngealized segments in the Afro-Asiatic languages tend to be coronals, although sometimes the uvular stop /q/ is interpreted as a pharyngealized velar stop /$k^ʕ$/. In Caucasian languages, pharyngealization is often found on uvular segments, and there are often more uvular segments with secondary articulations such as pharyngealization and labialization than plain uvular consonants.

In keeping with his description of primary pharyngeal consonants, Catford maintains that pharyngealization may be formed by retraction of the tongue root or through lateral compression of the faucal pillars and some raising of the larynx or by a combination of the two (Catford 1977:193). Ladefoged & Maddieson (1996:365) state that "comparison across languages suggests that there are distinguishable higher and lower secondary pharyngeal gestures." We will look at data on Arabic and Caucasian languages for information on the active articulator and the place of constriction, and on additional gestures accompanying the pharyngealization. We will also use acoustic data to compare similarity of gestures.

In Arabic, the primary emphatic or pharyngealized segments are the retracted coronals, [$t^ʕ$, $s^ʕ$, $d^ʕ$, or $ð^ʕ$], and additionally in some dialects such as Egyptian, [$z^ʕ$]. Some phonologists argue that other consonants must be considered emphatic as well, and we will review some of these arguments below. However, in general we will mean the coronal emphatics when using the term 'emphatics' or 'pharyngealized consonants' with respect to Arabic. We will first look at data regarding the location of the rear constriction (all of these segments have primary anterior coronal constrictions). There is much debate on whether these emphatics are actually velarized, uvularized or pharyngealized. Velarization would imply raising of the dorsum towards the soft palate, uvularization would mean pulling the dorsum back towards the uvula, and

[4]Arabic, Shilha, Tuareg (Tamasheq); Rutul, Archi, and possibly Nootka.

pharyngealization would imply a retraction of the tongue root. Velarization and uvularization as applied to Arabic mean essentially the same thing: that there is a constriction in the upper pharynx, although some Arabic descriptions use the word "velarization" when actually describing "pharyngealization". Ladefoged (1993:232) says that there is little difference between velarized and pharyngealized sounds and that no language contrasts the two possibilities. Both Ladefoged (Ibid.) and Catford (1977:193) agree that some Arabic emphatics are velarized/uvularized while others are pharyngealized. Laufer & Baer (1988) review some of the debate about whether the Arabic emphatics are velarized or pharyngealized; their own fiberscopic data on speakers from Lebanon, Iraq and Israel shows the constriction to be in the low pharynx between the epiglottis and the pharyngeal wall. In the x-rays of his own speech, Ghazeli (1977:72) found the secondary constriction to be much higher: "at the level of the secondary cervical vertebrae," which he later notes is midway between the place of articulation of uvulars and pharyngeals (Ibid.:174). The vertebrae are not shown in his published tracings; in some of my tracings of his film I have noted the second vertebra spanning a distance from just above the tip of the uvula (when the velopharyngeal port is closed) to slightly more than half of the way to the tip of the epiglottis, thus the movement is largely in the upper pharynx below the tip of the uvula. Laufer & Baer (1988:197) dispute Ghazeli's description, saying that in Ghazeli's x-rays, "the narrowest constriction is always between the epiglottis and the pharyngeal wall." Unfortunately, this seems to be true of their non-emphatic counterparts as well; for both emphatic and non-emphatic coronals the tip of the epiglottis marks the narrowest point in the pharynx. There is however a difference between the emphatic and non-emphatic coronals. Of the segments which I have traced, there is some variation between higher constrictions just below the tip of the uvula as in (1-9) [s, sˤ], and lower constrictions closer to the tip of the epiglottis as in (1-8) [t, tˤ].

Several linguists have noted an additional gesture in the articulation of coronal emphatics. Ghazeli (1977:72) found another component of pharyngealization in his speech to be "a depression of the palatine dorsum" - a lowering of the dorsum under the palate. Cowell (1964:6) describes something similar in Syrian Arabic: "the profile of the tongue tends to be two-humped and low in the middle; the back hump narrows the velar and pharyngeal passages." Erwin (1963:12) is more explicit when describing the emphatic consonants in Iraqi Arabic: "the central part of the tongue is slightly depressed and the back part raised, so that the upper surface of the tongue is concave..." Thus emphasis creates a slightly increased cavity under the palate and a reduced pharyngeal cavity above the epiglottis. Ghazeli (1977:73) did not find any contraction of the laryngopharynx, raising of the larynx or lip rounding accompanying emphatic segments in his speech.

Emphasis in Arabic has been shown to have the acoustic effect of lowering the second formant (Harrell, 1957; Obrecht, 1968; Al-Ani, 1970; Ghazeli, 1977; Card, 1983; El-Halees, 1985, among others). Ghazeli found this to be true of his speech, of which x-ray data show the constriction to be in the upper pharynx, and that of eleven other speakers from eight dialects. For Ghazeli's acoustic data, measurements were made at consonant-vowel transitions and mid-vowel. Average values of F_2 onsets adjacent to emphatic consonants [tˤ, sˤ] were 200 to 800 Hz. lower (depending on the vowel) than when adjacent to plain consonants [t, s]. Card also found a lowered second formant in the steady-state portion of affected vowels, the second formant in all fricatives, and offsets of obstruents in Palestinian Arabic.

Scholars and researchers differ on whether the uvular consonants [q, χ, ʁ] are considered to be emphatic. Ghazeli (1977:59-64) disputes this with articulatory and acoustic evidence showing that the uvulars only induce backing in adjacent low front vowels and have no effect on adjacent consonants, nor on low front vowels separated by an intervening consonant. Through acoustic data on nine dialects (Tunis, Sahel, Ghoumrassen, Tripoli, Jordan, Baghdad, Zaouia, Algiers, Cairo), Ghazeli also shows that in the majority of the dialects, the backing effect of uvulars on low vowels is less than that of pharyngealized consonants. In six of the nine dialects, average first formant values of the low vowel are the same when adjacent to uvular consonants as when adjacent to pharyngealized consonants, but the second formant values were 100-300 Hz. higher next to uvular consonants than when next to pharyngealized consonants; the Tunis and Baghdad dialects show a greater difference in the first formant values than in the second; while low vowels in the Cairo dialect show no backing next to uvular consonants at all.

Other consonants which have been argued to be emphatic or to form a minor series (Harrell, 1957; Cowell, 1964; Rice & Sa'id, 1979; Card, 1983) include /b, m, f, n, l, r, g, k/. The main basis for this argument is that they can all occur next to a back /a/. Ghazeli (Ibid:141) argues against including /b, m, f, n, g, k/ as " they are only back when next to [ɑ]. They do not remain back when they are adjacent to palatal vowels nor do they induce backing coarticulation effect on neighboring segments." Ghazeli argues instead that the distinction between æ/ɑ has become phonemic in North African dialects and that [ɑ] induces backing in neighboring consonants. The situation is different in Iraqi Arabic, where the non-back low vowel is central rather than front, and in which there are only a few examples of backed [ɑ] occurring independently of pharyngealized consonants, the most common being next to /l/. Iraqi Arabic has minimal pairs involving [l/lˤ] after [ɑ] in which [lˤ] has a much lower second formant (by 500 Hz.) than [l]. The situation regarding [rˤ] in the various dialects is much more confusing. In some dialects, there may be phonetic conditioning for some occurrences of [rˤ]: next to [a] or [u], pharyngealized consonants, or uvular consonants which are themselves adjacent to [a] or [u] (Ibid:153-4). In other cases it appears [lˤ, rˤ] must be recognized as separate phonemes. However, they do not induce backing in an entire word. Thus the phonological properties of [tˤ, sˤ, dˤ, or ðˤ, zˤ] are different from those of other consonants which have been argued to be emphatic, and we will limit our discussion to coronal obstruent emphatics in this dissertation.

Pharyngealized uvular segments are found in some Caucasian languages. In a number of Caucasian languages, there are multiple series of uvular consonants. Ubykh, a Northern Caucasian language of the Abkhazo-Adygan group, has the greatest number. It contrasts plain, rounded, palatalized, pharyngealized, and rounded pharyngealized uvulars for four segment types: voiceless stops, voiceless ejective stops, voiceless and voiced fricatives, yielding twenty segments (see Colarusso, 1975). It should be noted that there are no plain pharyngeal consonants. Colarusso (1975) provides spectrograms of twenty-one Ubykh words containing uvular segments and summary plots of their acoustic spectra. In these examples, Colarusso found that the "acoustic effects of pharyngealization are complex" (Ibid.:221). He suggests that there may be a noisy band of energy centered on 500 Hz. and sometimes other formants at 1100 Hz, 2000-2400 Hz. and 3300-4000 Hz. Some segments fit these generalizations and some do not. Colarusso also provides spectrograms of pharyngealized and non-pharyngealized labials. In the pharyngealized voiced bilabial stop, there are two extra bands of energy, one between 500-1000 Hz. and one just above 1000. Bands at these locations are also present in the transition into a voiceless pharyngealized ejective bilabial stop, but not in some of the other pharyngealized labials. This is rather different from the pharyngealization in Arabic, where Card (1983) and others have found a lowering of the second formant. Ubykh also has another interesting segment type, palatalized uvulars. Colarusso (Ibid.:264-5) argues that these segments have an advanced tongue root and that advancing the tongue root causes bunching of the tongue, which narrows the anterior oral cavity and simultaneously widens the pharyngeal one, yielding a lowered first formant and thus a palatalizing effect on adjacent vowels. This argument requires more research before it can be accepted (although unfortunately the language is now extinct).[5] But if the palatalized uvulars in Ubykh were truly formed by advancing the tongue root, we would have had a language which contrasts an advanced tongue root movement with pharyngealization, or retracted tongue root, in consonants.

Bzyb, a Northern Caucasian Abkhaz language, has only two pharyngealized uvulars, a voiceless pharyngealized uvular fricative and a voiceless labialized pharyngealized uvular fricative. Bgažba (1964) provides x-rays of both, along with one plain uvular fricative, and a pharyngealized uvular stop in Abaza. The labialized and non-labialized pharyngealized uvulars appear to have slightly different constriction locations, perhaps because each is from a different speaker. Both display a broader constriction than that of the plain uvular fricative, in which the tongue appears more tightly bunched. The non-labialized pharyngealized uvular fricative in particular displays fairly equal narrowing in both the uvular and upper pharyngeal regions. (1-10) superimposes a tracing of a plain uvular fricative with one of a non-labialized pharyngealized uvular fricative in Bzyb.

There are reports on other languages with emphatic segments which might be pharyngealized segments. These include Neo-Aramaic (Garbell, 1965; Hoberman, 1988), Shilha (Applegate, 1958), and Chilcotin (Cook, 1987). There is no acoustic or articulatory data on these languages, although the descriptions in some cases suggest a

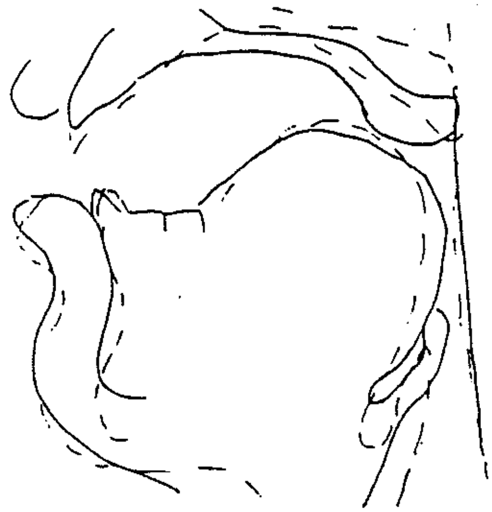
[5]Whether a lowered first formant alone yields a palatalizing effect also requires more research. Some research on formant frequency patterns of VCV utterances in Russian which differ in the palatalization/non-palatalization of the consonant has been done by Purcell (1979).

different articulation than in Arabic emphatic coronals. In Neo-Aramaic, a Semitic language related to Arabic, emphatic segments or flat phones are realized with a complex of phonetic features which vary according to the exact segment being produced:

> "Flat phones are produced in contrast to plain ones in the following manner: all oral consonants are strongly velarized; labials are produced with a marked protrusion and rounding of the lips; *r* is actualized as a trill; . . . all consonants (including *h*) are more or less pharyngealized according to the individual speakers..." (Garbell 1965:33)

All oral consonants are velarized and 'more or less' pharyngealized, but the realization of emphatic segments is helped by the other features. When we review the literature on languages with advanced tongue root we will find in some languages a different cluster of accompanying features.

Accounts of pharyngealization vary considerably in different languages. In this dissertation our x-ray data is limited to Arabic emphatic coronals. It is unfortunate that neither Leroy & Paris' nor Bgažba's x-ray data is suitable for quantitative analysis, as it would be interesting to compare pharyngealization in Caucasian languages with that in Arabic. In Arabic we wish to determine how and where pharyngealization is accomplished in the coronal emphatics, and compare these results with those on primary pharyngeal articulations, and with pharyngealized and [-ATR] vowels, which will be surveyed below.

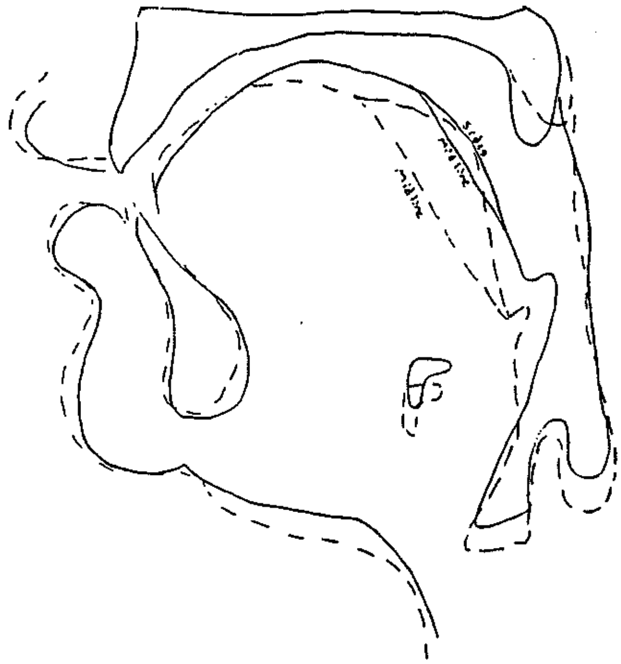


(1-10) Superimposed tracings of plain and pharyngealized uvular fricatives in Bzyb, from Bgažba (1964).

------- [χ] from Figure 28 ________ [χ^ʕ] from Figure 25

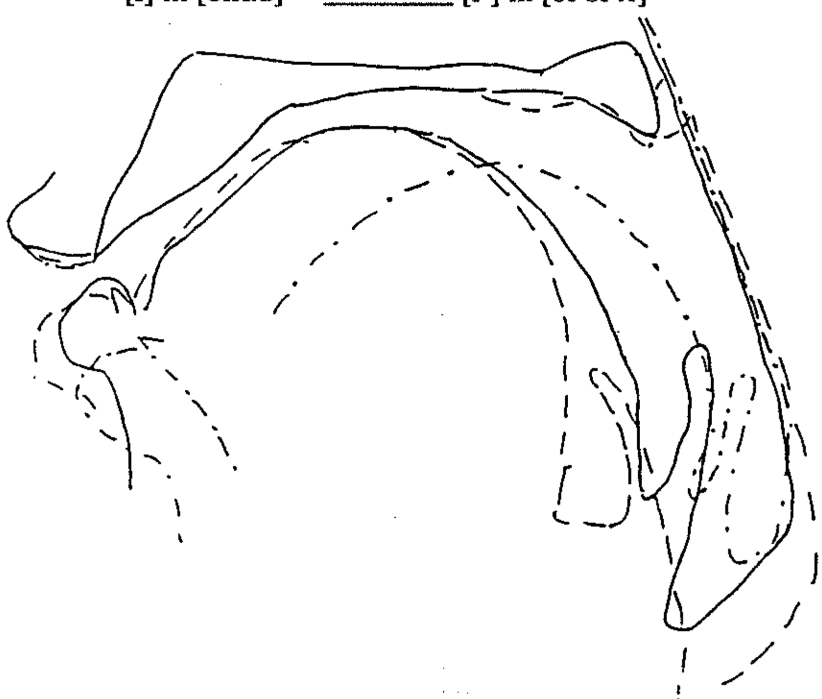
(1-11) Enlarged and superimposed tracings of [a] and [a^ʕ] in Udi from Gaprindašvili (1966a).

------- [a] in Figure 4 ________ [a^ʕ] in Figure 8



(1-12) Mid-sagittal tracings of [i] and [iˤ] from the x-ray film by Ghazeli.

------- [i] in [bifiːd] ________ [iˤ] in [biˤðiˤːʕ]



(1-13) Mid-sagittal tracings of [i], [ɪ], and [ɑ] of Akan Speaker 1 from originals by Lindau.

------- [i] ________ [ɪ] _._._ [ɑ]

1.2.4 Secondary Pharyngeal Articulation: Pharyngealization on vowels

In this section, we will first look at phonemic pharyngealization on vowels, and then at pharyngealization that can be described in terms of coarticulation. Contrastive pharyngealization on vowels is slightly more common than pharyngealization on consonants, and occurs in more language families. Maddieson (1984) lists five languages from the Ural-Altaic, Afro-Asiatic, Caucasian, and Khoisan language families (1.5% of data base). His expanded data-base includes one additional language from the Caucasian family.[6] X-ray data is available on Tsakhur and Udi (Gaprindašvili, 1966a), Dargi (Gaprindašvili, 1966b), Even (Norikova, 1960), and !Xóõ (Traill, 1985 and films). Examples from three of these languages are shown in Ladefoged & Maddieson (1996:306-310).

Catford (1977:182) describes pharyngealized vowels as involving a compression of the pharynx, usually by retraction of the tongue root, simultaneously with the vowel articulation. Inspection of x-ray tracings from just these four languages show that there is considerable variation in location of the constriction, and thus active articulator, and in accompanying gestures.

In Caucasian languages, pharyngealization as a phonological feature of vowels is limited to Dagestan. Although in some cases it is unclear whether pharyngealization is a property of the consonants or the vowels, in Tsakhur and Udi the pharyngealized vowels appear to form an independent series (Catford, 1989:3). X-rays of plain and pharyngealized vowels in these two languages appeared in Gaprindašvili (1966a) and are described by Catford (1989:10-11): "It is quite clear from these that there is indeed pharyngealization - the root of the tongue, with the epiglottis, can be seen projecting backwards into the pharynx. But at the same time there is a sulcalization, or hollowing,

[6]Evenki, Neo-Aramaic, Hamer, Lak, !Xũ; Archi.

of the dorsal surface of the tongue approximately opposite the uvula." Catford notes that this tongue shape is similar to that found in "a common variety of Midwestern /r/" (Ibid.: 11), and produces the same sort of lowering of F3. Looking at these x-ray tracings, the pharyngeal constriction is just above or at the level of the tip of the epiglottis, and the front constriction is located under the anterior portion of the hard palate. Udi /ɑˤ/ does appear to have more retraction of the tongue root than /ɑ/, but more noticeably, it has the pronounced raising of the front dorsum and the sulcalization beneath the uvula noted by Catford, perhaps to the extent that it should really be called palatalization rather than pharyngealization. See (1-11) for examples of [ɑ] and [ɑˤ] in Udi, after x-ray tracings by Gaprindašvili (1966a). Pharyngealized vowels in Dargi also display sulcalization under the uvula. In contrast, the pharyngealized vowels in the Tungus language Even (or Evenki) display a more evenly rounded shape with a general narrowing of the pharynx, and no sulcalization under the uvula. Ladefoged & Maddieson find the Even vowels similar to the vowel harmony vowels in Akan, but suggest that both the x-rays and the acoustic characteristics indicate a more narrow pharynx in the pharyngealized vowels of Even than in the [-ATR] vowels of Akan.

Maddieson (1984) notes that in a number of languages, such as Evenki (Tungus, Ural-Altaic), Hamer (Omotic, Afro-Asiatic), and Lak (Caucasian), the pharyngealized vowels are more centralized than the closest non-pharyngealized vowel. "These variations in vowel quality are reminiscent of the qualitative differences between sets of vowels in vowel harmony languages whose harmony is based on variable pharynx width (tongue root advancement)." (Ibid:132-133) Although Maddieson finds the two types similar, it should be noted that in the vowel harmony languages to which he referred, the qualitative differences usually do not involve centralization, as we will see in the next section.

The pharyngealization found in !Xóõ is rather different. !Xóõ is unusual in that it has two kinds of pharyngealization on vowels; neither are like the "two-humped" pharyngealization found in Tsakhur and Udi. (See (1-7) for tracings of three vowels of !Xóõ.) Traill (1985:67-9) analyzes !Xóõ as having five basic vocalic contrasts: /i e a o u/. These vowels may be underlyingly nasalized, breathy voiced, glottalized, pharyngealized and in various combinations of these (eight combinations are documented by Traill), however, [+pharyngealized] vowels may not be [-back]. X-ray pictures of the pharyngealized vowels, which Traill transcribes as [a̰, ṵ] in comparison with their non-pharyngealized counterparts, show that the bulk of the dorsum is lowered and the tongue root is very retracted (Ibid: 75). The shape of the tongue is neither rounded nor flat, but rather like a flattened pyramid. They are perhaps more similar to the Caucasian pharyngealized vowels, but in !Xóõ there is only a slight raising of the blade of the tongue. Ladefoged & Maddieson (1996:310) found the acoustic and auditory effects of pharyngealization in !Xóõ to be different in than in Tsakhur and Udi: "The lowering of the third formant in similar to that reported in the Caucasian languages; but in the Khoisan examples, there is also a considerable *raising* of the lower formants, accompanied by a diminution of energy around 400-700 Hz. This is comparable to the acoustic effects seen in pharyngeal consonants."

In addition, !Xóõ also has two vowels which exhibit extreme pharyngealization (Traill calls them "strident vowels"), see §1.2.2. In the strident vowels [a̰h, ṵh], the body of the tongue is depressed even further than was the case for [a̰, ṵ], and the cushion of the epiglottis is compressed against the arytenoid cartilages. Acoustically, the strident vowels are distinguished from the pharyngealized vowels in !Xóõ by "even more upward displacement of the second formant" and by irregular, noisy vibrations (Ladefoged & Maddieson 1996:313). The frequencies of the first formants in the two sets of vowels appear approximately the same (see Ladefoged & Maddieson 1996:309,312).

Non-contrastive pharyngealization of vowels occurs in Arabic. The vowels in Arabic dialects have retracted allophones when adjacent to emphatic consonants. The rules of emphasis spreading vary somewhat from dialect to dialect. Ghazeli's articulatory data on his speech show that in an emphatic word, all vowels are retracted in comparison with a non-emphatic word. Keating (1987) suggests that there may be a sort of register difference between words containing a pharyngealized consonant and those which do not, also that emphasis spreading is not phonological except to coronal obstruents. In the absence of a firm resolution on the status of emphasis-spreading in Arabic and as the difference between vowels in words containing an emphatic or not is quite substantial, we will include the pharyngealized vowels of Arabic in our study in order to examine their articulatory similarity to other pharyngealized segments. For instance, a relevant proposal by Lindau (1975) is that pharyngealized consonants and vowels in Arabic, along with vowel harmony languages like Akan, may also use her proposed feature [Expanded].

Ghazeli found the greatest articulatory difference between retracted and non-retracted vowels to occur along his measurement line DE2, a radius line originating below the center of the tongue mass and passing through the tip of the uvula at rest position (i.e., when the velopharyngeal port is open) but probably not when the uvula is raised during speech. Line DE4, two radii lower, passes through the epiglottis at rest. The movement described is thus in the very upper pharynx. The radius lines are oblique rather than perpendicular to the surface of the tongue, and thus less satisfactory for measurement purposes. New tracings of [i] and [iˤ] from the x-ray film by Ghazeli are shown in (1-12). Both vowels display a lowered central groove and raised sides at the rear dorsum, although since the groove in [i] is much deeper than in [iˤ], we find a substantial difference between the two centered in the upper pharynx.

Emphasis or flattening of vowels appears in other disparate languages. In the Semitic Afro-Asiatic language Neo-Aramaic (Garbell, 1965; Hoberman, 1988), flattening or emphasis appears to be the property of the syllable which affects all segments including vowels, which are backed and lowered. In the Berber Afro-Asiatic language Shilha[7] (Applegate, 1958), there are seven emphatic consonants, six coronal and one velar, which back or lower adjacent vowels. The North American Northern Athabaskan language Chilcotin (Cook, 1987) has bidirectional flattening induced by three series of consonants, two uvular and one coronal, where the vowels are "laxed". Unfortunately, there is no published acoustic or articulatory data on these languages.

The behavior of vowels adjacent to pharyngeals, and in some cases uvulars, is different from emphasis connected with pharyngealized coronals. There is some acoustic data on Nxaʔamxčin, an Interior Salish language of North America (Bessell, 1991), on vowels preceding uvular and pharyngeal consonants. Before uvular, pharyngeal and labialized pharyngeal consonants, the nuclei of the vowels /i, a, u, ə / have a raised first formant, and /i/ also has a lowered second formant. The effects on the second formant of other vowels do not appear to be substantial. Bessell compares her data with that from Alwan (1986) on Iraqi Arabic which displays raising of the first formant of the vowels /i, u/ after a pharyngeal or uvular consonant and of /a/ after a pharyngeal consonant but not a uvular one (in the latter case F_1 is actually lowered because the F_1 of uvulars is about 500 Hz.). Ghazeli (1977) provides data on vowels in Tunisian Arabic and several other dialects: adjacent to pharyngeals, F_1 is raised and F_2 displays a pronounced transition while adjacent to uvulars, F_2 is consistently lowered

[7]Shilha is also known as Tashlhiyt.

and F_1 raised for /a/ only if it is a front [ɛ, æ]. Generally in Arabic, the effects of pharyngeals and uvulars on the quality of adjacent vowels can be ascribed to coarticulation (Ibid.:50), although the occurrence of the low vowel /a/ is in some cases phonologically conditioned by the presence of a pharyngeal consonant in the root (McCarthy 1994). The influence of pharyngeals and uvulars seems to be limited to adjacent vowels in these three sets of data and do not show the longer-ranging effects of emphasis. Acoustically, pharyngeals tend to raise the first formant of adjacent vowels while emphatic coronals, and in some cases uvulars, tend to lower the second formant. It should be emphasized that the effects on vowels of emphatic coronals in Arabic are different from those of pharyngeal consonants, both acoustically and phonologically.

While we will not be able to address the description of pharyngealization of vowels in Caucasian and Amer-Indian languages, we will be able to examine the vowels in emphatic words in Arabic and the two kinds of pharyngealization found in !Xóõ. We will be able to examine how they are articulated and compare them with emphatic coronals in Arabic, [-ATR] vowels in two African languages, and primary pharyngeals in Arabic.

1.2.5 Advanced Tongue Root vowels in languages with vowel harmony

Many African languages in the Niger-Kordofanian and Nilo-Saharan language families display a form of vowel harmony in which the vowels are divided into two harmony sets. Vowels from different harmony sets cannot co-occur freely: their occurrence within a word is strictly governed by phonological rules. As the vowels in each set include vowels of different heights, it has been referred to as cross-height vowel harmony. For instance in Akan, vowels within a word generally only contain Set 1 vowels [i, e, o, u] or Set 2 vowels [ɪ, ɛ, ɔ, ʊ]. The main exception in Akan is the low vowel [ɑ], which may occur with either set. We will first discuss some of the phonological features proposed for these vowels as they are different from the ones proposed for pharyngeal consonants (§1.1). In §1.2.5.2, we will discuss the articulatory data.

1.2.5.1 Feature proposals for vowel harmony languages

In the past, the distinguishing feature between the vowel harmony sets was referred to as "tense/lax", "muffled/brassy", "hollow/hard" etc. Ward (1937), as cited by Stewart (1967), seems to have been the first to describe the articulatory basis "in the case of Abua, a Nigerian language, ... to be 'wide pharynx with breathy somewhat hollow voice' as opposed to 'pharyngeal constriction'" (Stewart 1967:199). Ladefoged (1964) was the first to supply concrete evidence of the actual position of the tongue in the form of x-rays of a speaker of Igbo, and suggested that the terms 'narrow/wide' as used by Sweet (1906) to refer to the pharynx might be appropriate. Stewart (1967) described the phenomenon as advancing the tongue root, and Halle & Stevens (1969) used the term Advanced Tongue Root as the name of a feature.

The name of the feature [Advanced Tongue Root] implies a very concrete articulatory basis: movement of the tongue root to widen or narrow the pharynx. However, almost from the very beginning, it has continued to be equated with the tense/lax distinction and thus with the dimension of tongue height. Based partly on four x-rays of two tense/lax vowel pairs in English, Halle & Stevens (1969) argue that the tense/lax distinction in English arises from a difference in tongue root position and thus is similar to the vowel harmony feature found in West African languages. Lindau (1979) counters this proposition for both articulatory and acoustic reasons. First, Lindau finds the English vowels as shown in Perkell (1971) to have "equal or larger differences in tongue height between the members of each pair so that there is no indication that the tongue root is used for anything else than raising the highest point of the tongue" (Lindau 1979:175). She also notes that Ladefoged et al. (1972) show that "only two or three out of six speakers of English used the tongue root mechanism for distinguishing between the two classes of vowels in American English (ibid.)." In her own study of Akan, Lindau found tongue root position to be independent of tongue height in distinguishing the vowel harmony sets and consistently used by all four speakers. Second, Lindau argues that acoustically the English lax vowels tend to be more centralized than their tense counterparts, whereas in Akan the two sets differ mostly in the first formant. She concludes that there is a consistent articulatory mechanism enlarging or contracting the pharyngeal space through both tongue root movement and larynx movement in Akan while the tenseness feature in English "does not seem to be related to any unique articulatory mechanism" (Lindau 1979:175). She believes that "it is probably best described in terms of an auditory-acoustic feature Peripheral, as proposed by Stockwell (1971)" (Ibid.).

Archangeli & Pulleyblank (1992:146-148) take a different position on the relation of tense/lax and [ATR]. While they accept that the phonetic arguments made by Lindau for Akan are correct, they analyze [ATR] and [tense] as manifestations of a single feature because 1) there is a tendency in other languages for tongue height and tongue root advancement to be correlated and 2) [ATR] and [tense] appear to be in complementary distribution at a phonological level, that is, they do not occur in the same language. However, according to Lindau (1987), Agwagwune has both [ATR] harmony and laxing of every vowel in closed syllables. Keating (1987:136) concludes "that at least for phonetic descriptions, [ATR] must be kept distinct from [tense]." Collapsing [ATR] and [tense] will also obscure the generalization that rules involving [ATR] in a vowel harmony language are different on the whole from those involving [tense] in a Germanic language. One loses not only the phonetic differences but the systemic differences as well. If one still wishes to unite [ATR] and [tense] phonologically, it would be less confusing to create a new term which does not have historically associated phonetic definitions. Or one could define different types of "[ATR]". In Akan, [ATR] could be defined as Pharyngeal, while in English, [ATR] would not be defined as Pharyngeal since there are equal movements of the tongue dorsum and the tongue root.

A second problem with the name [ATR] is its implied reliance on the tongue root. For instance, in Nilo-Saharan languages, the extent to which advancement of the tongue root underlies the vowel harmony system has been questioned. Jacobson (1978:76) concludes that speakers of Dho Luo use tongue root or tongue height or both to make the vowel harmony distinction. In Dinka, Jacobson (1980) found that only the back vowels were distinguished by advancement/retraction of the tongue root. Other writers, such as Malou (1988), conclude that phonation differences underlie the distinction in some of these languages. This has been corroborated by Denning (1989) for one speaker of Bor Dinka, as Denning found that two measures of spectral tilt (F_0-H_2 and F_0-F_1) showed the expected differences for breathy and modal vowels. In some of these languages we may want to nominate a different feature instead of [ATR] as the one involved in vowel harmony.

Archangeli & Pulleyblank (1992) adopt the hierarchical feature structure of Sagey (1986) with an additional articulator node, [pharyngeal], under which they place [ATR]. The most far-reaching effects are not for a 'true' [ATR] language like Akan, but for a language like English, where the tense/lax vowel distinctions can now be represented by an articulator node in a hierarchical feature structure. Their tree structure is much simpler than that found in Ladefoged (1994), Halle (1989), McCarthy (1994), or Keyser &

Stevens (1994), who redefine and rearrange the structure espoused in Sagey (1986) considerably. Archangeli & Pulleyblank do not explicitly address the relationship of [ATR] with pharyngeal segments, but presumably they would also be assigned [ATR] under the [pharyngeal] node.

Another issue which has never been satisfactorily resolved is whether we need different categories for degrees of advancement or retraction of the tongue root. Part of the answer lies in whether we are providing phonological or phonetic definitions for features. Lindau (1975) emphasizes the observed similarities among pharyngealized consonants and vowels in Arabic and vowel harmony involving the tongue root by using the feature [Expanded] for all of these segments. The phonetic values of [Expanded] divide the pharynx in both the horizontal and vertical dimensions. The phonetic values provide three tongue root positions, advanced, neutral and retracted, and two larynx positions which are combined with tongue root positions (larynx lowering with advanced and larynx raising with retracted) to expand or contract the pharynx as much as possible. Lindau (1975) does not make specific reference to uvular and pharyngeal consonants, but has said (p.c.) that she would have followed Williamson (1977), which distinguishes values for uvular, pharyngeal and glottal (in the oropharyngeal area) under her multi-valued place feature. As such, [Expanded] would be a feature which defines a secondary articulation and which cuts across (i.e., may be combined with) all other primary places of articulation. This makes the prediction that we should find place differences in where the tongue is retracted or advanced, e.g. uvular, pharyngeal, etc. Such a feature also suggests that there is a distinction in the type or make-up of the pharyngeal component between segments with a primary articulation in the pharynx, such as pharyngeal consonants, and those with a secondary articulation, such as pharyngealized consonants and vowels.

Anderson (1974) proposed a somewhat similar division along the horizontal axis of the pharynx with the features [Advanced Tongue Root] and [Retracted Tongue Root], but classified the segments in question somewhat differently. He defined pharyngeals and pharyngealized sounds, and what we would consider to be [-ATR] vowels as distinctively [+Retracted Tongue Root] (= narrow pharynx) rather than [+low], which is retained for use with ordinary low vowels. He thus separated consonants and segments with secondary articulations in the pharynx from ordinary vowel gestures. Keyser & Stevens (1994) and Halle (1989), discussed in the previous section, also provide a separate feature [constricted pharynx] distinct from [ATR]. Goad (1989) also argues that [RTR] is a separate feature from [ATR] on the basis of Chilcotin phonology. In making this argument, she assumes that flattening in Chilcotin is articulated by the tongue root, but no articulatory evidence is presented. Other alternatives are possible; for instance, the movement could be implemented by the rear dorsum. We will reconsider this issue in light of our articulatory analysis of Arabic emphasis, to which it shows many similarities, in later chapters.

A somewhat different analysis of [ATR]/[RTR] phenomena is presented by Czaykowska-Higgins (1987). She separates languages with [ATR] ("Type I": Mon-Khmer group, Akan, Dho-Luo, Igbo, Babine) from languages in which there is a relationship between vowel quality and presence of uvular, pharyngeal, or retracted consonants ("Type II": Arabic, West Greenlandic Eskimo, Interior Salish). She does not propose features to represent [ATR] in Type I languages, but argues that they must be different from the features used to represent uvular and pharyngeal consonants and retraction in Type II languages. For the Type II languages, she posits a Tongue Root Articulator with divisions of [Upper Pharynx] and [Lower Pharynx], which would be in a retracted position when activated. Her proposal for Type II languages is equivalent to [RTR] with a subdivision into [Upper Pharynx] and [Lower Pharynx]. In our analyses of Akan and Arabic, we will determine to what extent these articulations can be phonetically united or separated.

Above we have discussed several issues: which articulations are similar enough to [ATR] to be combined with it (i.e., [tense]), the problem of languages which do not consistently use [ATR], and whether we need separate features representing advancement of the tongue root from retraction or perhaps various phonetic degrees of advancement and retraction. To some extent the debate reflects a lack of data on what is typical of the various languages, but it also reflects a need to re-examine these proposals in terms of what is needed in the phonologies and how the features are then phonetically implemented. Our analysis of Akan and Arabic in subsequent chapters will investigate the articulatory similarity of the advancement and retraction of the tongue root found in the [ATR] language Akan, with a language which emphasizes retraction of the tongue root (and perhaps the rear dorsum) in the production of pharyngeals and pharyngealized segments. Below we will discuss what is known about the articulatory positions of these vowels through work by Ladefoged (1964), Painter (1973), Lindau (1975, 1978, 1979, 1987), Jacobson (1978, 1980), Gueye (1986), Jackson (1988a,b), and Tiede (1993, 1996).

1.2.5.2 Articulatory position of [±ATR] vowels

Maddieson (1984) does not separately list languages which base vowel harmony on pharyngeal width or tongue root advancement:

> "In the vowel harmony languages there does not seem to be a strong percept of pharyngeal constriction for the vowels in the set with narrow pharynx. Instead, the vowels in the two sets are usually well-distinguished auditorily by the basic parameters of vowel quality, and they have been represented in UPSID on this basis." (Maddieson 1984:133)

Although Maddieson does not identify vowel harmony languages in his data-base, we can make a rough estimate. Most of the languages with seven or more vowels in the Niger-Kordofanian and Nilo-Saharan families, of which there are thirty-four, have been analyzed in terms of [ATR], yielding a sample of almost eleven percent of the data-base. Thus of the segments with an articulation in the pharynx, [±ATR] vowels are the most common.

Ladefoged (1964:38) presents tracings from a cine-radiology film of eight vowels as spoken by one speaker of Igbo. For the high vowel pairs [i, e] and [u, ɷ], there is virtually no difference in the position of the tongue tip, blade and front dorsum, but a huge difference in the amount of retraction of the rear dorsum and tongue root. The area of divergence begins under the soft palate and becomes quite large below the uvula in the pharynx and continues down beyond the level of the pocket of the epiglottis. The laryngopharynx is not shown, but the tracings of the pairs of vowels are so far apart just below the pocket that there must be differences in the laryngopharynx as well. In the low vowel pairs [ɛ, a] and [o, ɔ], the difference in tongue root position is less striking as there are apparently equally large differences in the position of the front of the tongue as in the rear dorsum and tongue root. It is difficult to say whether the magnitude of the tongue root movement is greater than that of the front of the tongue, and Ladefoged does not provide any measurements to quantify the differences. In the pair [ɛ, a], the area of divergence occurs from the palate to the pocket of the epiglottis, but below that the two vowels are close to merging. The situation with [o, ɔ] is similar except that the retraction occurs closer to the uvula and would appear to extend further into the laryngopharynx. Visual inspection of the high vowels clearly shows that the primary pair-wise difference lies in the amount of advancement/retraction of the rear dorsum and tongue root, with the greatest degree occurring roughly at the level of the pocket of the epiglottis. With the low vowels, advancement/retraction appears to be implemented more by the rear dorsum as it occurs to a greater degree above the pocket of the epiglottis.

Painter (1973) made and examined mid-sagittal cine-radiographic tracings of 92 syllables of the Kwæhu dialect of Twi (Akan). For each vowel he made eleven measurements, of which six were of pharyngeal width, tongue root and epiglottal positions at two different levels in the pharynx. He concludes that "there is little to choose between the various pharyngeal and tongue root measurements (except EVW [epiglottal ventrical width]) since all show clearly and almost to the same degree that within any vowel pair the tense vowel has a wider pharynx than the lax one....it is nevertheless not the case that the five tense vowels as a set have wider pharynges than all the lax vowels as a set." (Painter, 1973:117). However as the location of the upper and lower measurements varies from vowel to vowel, they are difficult to compare directly and one cannot tell where in the pharynx the greatest degree of tongue root advancement/retraction is taking place. He also does not perform a statistical analysis to determine whether pharynx widening is independent of tongue height.

Lindau (1975) provides the largest amount of data to date on five different African languages: still x-rays of one speaker each of the Akyem dialect of Akan, the Umuchu dialect of Igbo, the Okrika dialect of Ịjọ, and Ateso, as well as cine-radiographic tracings of one speaker of Dho-Luo and four speakers of Akan (three of the Akyem dialect and one of the Ashanti dialect). (1-13) shows tracings of [i], [ɪ] and [ɑ] for one speaker of

Akan. She made several important findings. First, in the Niger-Congo languages Akan, Igbo and Ịjọ, she demonstrated that the feature underlying vowel harmony is not produced solely by advancement or retraction of the tongue root, but by expansion and contraction of the pharyngeal cavity through coordinated movements of the tongue root and larynx. Thus for an advanced tongue root vowel ([+ATR]), the tongue root is advanced and the larynx is lowered. (Jackson, 1988a, who included measurements of pharyngeal wall position in his re-analysis of Lindau's Akan tracings, showed that the pharyngeal wall also plays a role in expanding or contracting the pharyngeal cavity.) Second, although pharynx width is usually dependent on tongue height in languages like English, the same is not true of these Niger-Congo languages. In all three cases, after subtracting out the amount of pharynx width that is correlated with tongue height, two-way analyses of variance on the residuals showed that pharynx width is still highly correlated with vowel harmony set affiliation (Lindau, 1975: 49, 57, 64, 112). The same statistical procedure on tongue height revealed that it did not serve to distinguish vowel harmony sets. Third, using paired t-tests, she demonstrated that larynx height is significantly related to the vowel harmony feature in these three languages (Lindau, 1975:49, 59, 65, 112). In addition, she found differences between languages in the degree of tongue root retraction: the tongue root in Igbo was actively retracted (Lindau, 1975:57), while in the other languages it was merely non-advanced.

The situation in the Nilo-Saharan languages Ateso and Dho-Luo is different. In Ateso, there are large pair-wise differences in the position of the tongue root, but tongue height is affected to the same degree. The larynx does not vary between vowels of different sets (Lindau, 1979:70). In Dho-Luo, the position of the tongue root and tongue height are independent, but the degree of tongue root advancement is not as great as in the Niger-Congo languages, and is only significant for each vowel pair and not for the two vowel harmony sets as a whole (Lindau, 1979:75). Larynx position was not shown in her x-rays of Dho-Luo. Lindau did not observe phonation differences in her Ateso and Dho-Luo speakers as has sometimes been described, although she mentions that she has heard other Dho-Luo speakers contrast breathy voice with tense or creaky voice (Lindau, 1975:72).

Visual inspection of Lindau's Akan tracings reveals differences in the positions of both the front blade/dorsum and the rear dorsum/tongue root. Without measurements and statistical analysis, it would have been difficult to judge whether the magnitude of tongue root movement was greater than that of the front of the tongue. Comparison of tracings from speakers of different languages reveals differences in whether the rear dorsum is involved with the tongue root in forming the contrast between vowels of different harmony sets. In Akan, it would appear that the majority of the movement comes from the tongue root, while in Umuchu Igbo, the rear dorsum also appears to be involved in making the contrast. In Ateso, it seems to vary by vowel pair. Lindau measured the position of the tongue root only at about the level of the tip of the epiglottis and thus does not provide any information on the degree of activity of the rear dorsum.

Jacobson (1978) made x-ray tracings of eight speakers of Dho-Luo for eight high and mid vowels and presents three factor analyses (two three-factor analyses and one four-factor analysis) of the data. A vowel harmony factor is isolated in all three analyses, but in each case movement in the pharynx is balanced to some extent by movement of the front dorsum: as the tongue root retracts, the dorsum lowers, and vice versa. In two of the three analyses, the magnitude of the movement of the tongue root in the vowel harmony factor is clearly greater than that of the front dorsum, but in the third analysis, the magnitude of the two movements seems approximately equal. Jacobson (1978:76) concludes that "there are four factors for accounting for the contrasts in the

Dho Luo vowel system, but that any given speaker may choose them differently. All speakers will have the front/back component, but a speaker may select for using height or tongue root or both for maintaining the phonological contrasts among vowels." Examination of his analyses and visual inspection of the data suggest that Jacobson is overstating the amount of variability for his sample of speakers. When we examine his tracings we find, in the greater majority of cases, that pair-wise the tongue root is more advanced for [i, e u, o] than for [ɪ, ɛ, ʊ, ɔ], and in most of these the larynx is also lower, as in Akan. It is also true that there are differences in tongue height for most vowels (as Lindau found), but, after making simple measurements of pharynx width and tongue height, Jacobson himself says "pharynx width is a better indicator of vowel harmony category than tongue height is" (Jacobson, 1978:31). For two speakers, [ʊ] behaves more like a [+ATR] vowel as it has a wider pharynx and a higher tongue position than [u]. These same two speakers have negative loadings for the vowel harmony factor isolated in the four-factor analysis. In addition, for one of these speakers, the larynx is higher for [+ATR] vowels than for [-ATR] vowels. Jacobson does not mention whether any of the speakers he x-rayed also had voice quality differences, but it leaves us to wonder whether these two speakers use some other mechanism for differentiating the vowel harmony sets.

Jacobson (1980) compared the implementation of vowel harmony in three Western Nilotic (a branch of Nilo-Saharan) languages using x-rays of one speaker of Dho-Luo, two speakers of Shilluk and two speakers of Dinka. The Dho-Luo data presented in this paper displays a greater amount of tongue root advancement than tongue height variation, and systematic variation of larynx position. In Shilluk, tongue height varies with tongue root position, but no measurements are provided to determine the extent to which they are linked. Larynx height varies with vowel harmony set membership, but to a lesser extent than that displayed by the Dho-Luo speaker.

We will consider the data on the third language discussed in Jacobson (1980) separately, as a phonological analysis of Dinka as a vowel harmony language is somewhat problematic. It is also a particularly interesting language, as it appears to use a combination of both tongue root advancement and phonation differences to mark vowel differences. In Dinka, words are predominantly mono-syllabic and vowel harmony does not spread to contiguous words. Instead, there are morphological alternations marked by changes in vowel quality between semantically related words, such as between singular and plural nouns (Malou, 1988:38). In some of these alternations, Malou finds the difference to be between breathy and modal vowels. Breathiness of these vowels was confirmed by observation through a fiberoptic tube (Malou, 1988:33). Denning (1989) found that two measures of spectral tilt (F_0-H_2 and F_0-F_1) showed the expected differences for breathy and modal vowels for one speaker of Bor Dinka. Jacobson (1980:189-190) found with four front vowels that raising of the tongue corresponded with advancing of the tongue root and lowering of the larynx, and thus tongue root advancement is apparently not independent of tongue height. For back vowels he found that tongue height was virtually identical for all four vowels and "it is only the width of the pharynx - which, incidentally, corresponds to vowel height - and the degree of lip opening - which is greater for the relatively higher set - that separates these vowels articulatorily" (Jacobson, 1980:191). His tracings of back vowels show pharynx width to be greater for both members of one set than the other (Jacobson, 1980:190). It is not clear whether tongue root advancement is significant in separating front vowels, but for back vowels it is the major determinant in vowel quality. This may be a language then in which there are both voice quality differences and differences in tongue root position.

Gueye (1986) published a full set of x-ray tracings of short and long vowels for one speaker of Ndut. Ndut is a vowel harmony language spoken in Senegal, belonging to the West Atlantic branch of Niger-Kordofanian. Within the short high vowel pairs [i ɪ] and [u ʊ], the position of the front of the tongue is virtually identical, and differences are found only in the position of the tongue root and larynx. The short mid vowel pair [e ɛ] and the low vowel pair [ə a] display differences in the positions of the front and rear dorsum, but there are even larger differences in tongue root and larynx positions. The long front vowel pairs [iː ɪː] and [eː ɛː] are similar to the short high vowel pairs in that there are no pair-wise differences in tongue height - only differences in tongue root position and larynx height. The remaining long vowel pairs [uː ʊː] and [əː aː] display differences in tongue height as well as in tongue root position and larynx height.

Lindau (1987) and Jackson (1988a) re-analyzed Lindau's earlier tracing of Akan using PARAFAC[8]. Lindau (1987) made only sixteen measurements along the surface of the tongue for each vowel, while Jackson (1988) made forty-four, including measurements of the dorsal wall of the pharynx, larynx height, velum, and lip and jaw positions. Lindau analyzed the eight high and mid vowels which are paired off in different harmony sets; Jackson included two real tokens of the low vowel [ɑ] and let PARAFAC provide estimates for two other tokens (discussed further in §4.4). Lindau obtained two factors through her analysis, with the second factor dividing the vowel harmony sets through large amounts of tongue root advancement and retraction. Jackson extracted three factors, the third of which corresponds to the division in vowel harmony sets. Jackson's vowel harmony feature generates large amounts of larynx displacement and small movements of the rear dorsum and tongue root, which begin under the soft palate and continue down into the laryngopharynx. The articulatory

[8]PARAFAC is a factor analysis program developed by Richard Harshman and is described in §3.4.

correlates of Jackson's vowel harmony feature are somewhat surprising, but a different kind of analysis later in his work has results more in line with what we might expect. Jackson later derives a model of articulatory primes (independent articulatory gestures) through a pooled analysis of Akan, Chinese, and French data. When testing his hypothesized eleven articulatory primes against his Akan data, one of the six primes selected was one which combines large amounts of tongue root movement (in the laryngopharynx), larynx raising and pharynx wall movement, acting in concert to expand or contract the pharynx, which is closer to what we expected from examination of x-rays and from Lindau's analyses.

Tiede (1993, 1996) has used MRI to investigate pharyngeal volume in Akan and English vowels. He found that Akan showed consistently larger cross-sectional dimensions both above and below the pocket of the epiglottis for [+ATR] variants, while English tense vowels had larger volumes than corresponding lax counterparts only in the area above the pocket of the epiglottis (Tiede, 1996:419). He suggests that active control of the medial pharyngeal constrictor may be responsible for the different behavior in Akan.

In sum, the Niger-Kordofanian languages (for which we have x-rays) display a greater reliance on movement of the tongue root and larynx to form the vowel harmony distinction. In many cases, there is virtually no change in tongue height position but large changes in tongue root and larynx position. There are differences in the degree of tongue root retraction in the different languages. There are also differences in whether just the tongue root is retracted (Akan) or whether both the rear dorsum and the tongue root are backed (Umuchu Igbo). Lindau suggested retraction of the tongue root in vowel harmony languages may be similar to retraction in Arabic emphasis, which is a matter we will investigate below. The Nilo-Saharan languages that have been investigated do make use of the tongue root in the majority of cases, but tongue root movement is not as independent of tongue height movement as in the Niger-Kordofanian languages. The Nilo-Saharan languages make less use of systematic raising and lowering of the larynx, but may make greater use of phonation differences in forming the vowel harmony distinction. Below we will discuss the relationship of [ATR] with voice quality differences.

1.2.5.3 [ATR] and breathy voice

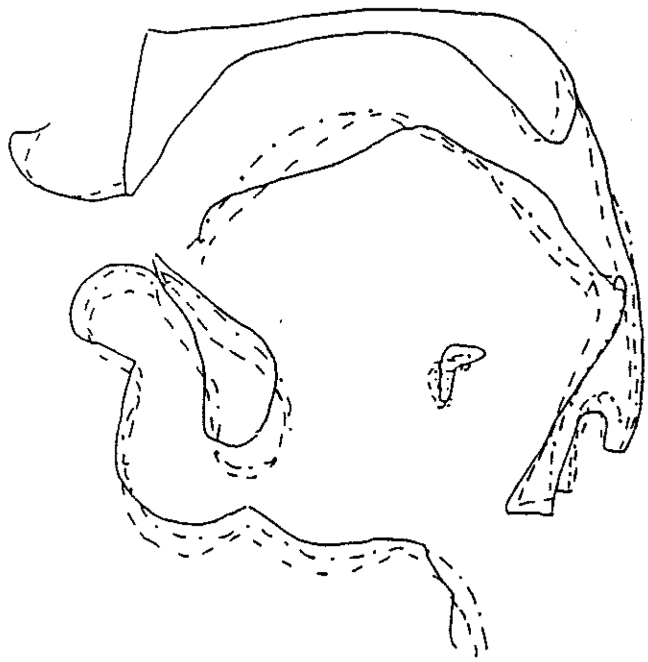
In the previous section we mentioned that the Nilo-Saharan language Dinka apparently uses both [ATR] and alternations between breathy and modal vowels in its vowel system. There are many reports in the literature on African vowel harmony systems associating advanced tongue root vowels with breathiness (Berry, 1955; Berry, 1957; Tucker & Bryan, 1966; Welmers, 1973; Jacobson, 1978; Jacobson, 1980). However, many languages with [ATR] do not exhibit breathy voice, e.g. Akan (Hess, 1992) and Igbo (Ladefoged, 1964). Many of the reports of breathiness and creakiness related to tongue root features are concentrated in the Nilo-Saharan languages of Africa (Tucker & Bryan 1966; Welmers, 1973:28; Jacobson 1978, 1980). Research on some of these languages (Jacobson, 1978, 1980; Lindau, 1975; Malou, 1988; Denning, 1989) indicates that some speakers of these languages substitute tongue raising and voice quality modifications for tongue root advancement and retraction. This implies that tongue root movement is not itself responsible for the modifications in voice quality. In addition, it has been shown by x-rays that at least one Mon Khmer language, Nyah Kur (Chao Bon), which has phonological distinctions between clear or normal voice and breathy voice, does not show any accompanying movements in the tongue root (Thongkum, 1982), despite the speculations by Gregerson (1976) that these properties co-occur in Mon-Khmer. A further example of the independence of larynx and tongue root control can be seen by comparing English and Akan. In American English the larynx is raised for /i/ and lowered for /a/ (Ewan & Krones, 1974), while in Akan, the larynx is lowered for [+ATR] vowels such as /i/ and raised for [-ATR] vowels such as /a/ (Lindau, 1979, Jackson, 1988). We will thus assume in our discussion on features that control of the tongue root, vertical larynx movement and voice quality should all be represented separately.

1.2.6 The low vowel /a/

Feature systems often assign one or more of the same features to low vowels and pharyngeal consonants. In this dissertation we will be interested in examining this assumption as the low vowel /a/ appears to present a conundrum: in many vowel harmony languages the only low vowel ([ɑ]) is [-ATR] (produced with a retracted tongue root) and is often opaque to vowel harmony, yet in Arabic, the low vowel has a fronted allophone when adjacent to pharyngeal consonants. For example, in the vowel harmony language Akan, /ɑ/ is the most retracted of the [-ATR] vowels, and its fronted allophone [æ], which occurs only before the high [+ATR] vowels /i,u/, still has a retracted tongue root (Lindau, p.c., from examination of her x-ray tracings). However, in §1.2.1, it was described how the front of the tongue dorsum is raised and fronted in Arabic pharyngeals and that the low vowel is fronted adjacent to these pharyngeals. In the Interior Salish language Nxaʔamxčin (Bessell, 1991), /a/ is fronted before a voiceless pharyngeal (indicated by a raised F_2) and Bessell points out that the pharyngealized /aˤ/ in the Caucasian Lezgian languages Tsakhur and Udi is also fronted (Catford, 1983). Gaprindašvili's (1966) tracing of Udi /aˤ/ shows a raised and tightly bunched fist-like front dorsum paired with a bulge at the epiglottis in the pharynx while the tracing of Tsakhur /aˤ/ shows a somewhat less extreme articulation, although it very definitely has a raised front dorsum and a retracted tongue root.

Comparison of new tracings made from the cinefluorographic film of Ghazeli of Tunisian Arabic in (1-14) shows that the back low vowel [ɑ] in [tɑːb] and the pharyngeal [ħ] in [ħæːli] have very retracted tongue roots, while the tongue root is less retracted in the following [æː] of [ħæːli]. The front dorsum is more raised in [ħ] than in [æː] and both of the former are quite different from the tongue profile of [ɑ]. Delattre's (1971:130) x-ray tracings of Lebanese Arabic (see (1-2)) also show that the tongue dorsum in the pharyngeal consonants /ħ, ʕ/ is raised and fronted to a greater degree than the following low vowel.

A plain low, back /a/ and a pharyngeal consonant with a low tongue profile would both have a high F_1 and a medium low F_2, bringing the first two formants close together. Interestingly, bringing F_1 and F_2 together is not the object in three unrelated languages with pharyngeal consonants, rather the articulation is modified to bring F_2 and F_3 together: The low vowel next to pharyngeals in Arabic and Nxaʔamxčin and the pharyngealized /aˤ/ in Tsakhur and Udi all have a somewhat raised F_2 and fronting of the tongue. The second constriction near the palate also produces a lowering of F_3, attested in Delattre's (1971) data on Lebanese Arabic, Catford's (1983) data on Udi but not Tsakhur, and mentioned in Bessell (1991) for the voiceless pharyngeal in Nxaʔamxčin only, thus bringing F_2 and F_3 closer together. As the tongue is fronter in (1-14) for the pharyngeal than for the vowel, we can argue that this should be regarded as a secondary articulation on the pharyngeal rather than influence of the vowel on the pharyngeal, at least for Tunisian Arabic.



(1-14) Mid-sagittal tracings of [ħ], [æ] and [ɑ] in Tunisian Arabic from the x-ray film by Ghazeli.

_ . _ . _ [ħ] in [ħæːli] - - - - - - - [æ] in [ħæːli] ________ [ɑ] in [tˤɑːb]

1.2.7 Summary

So far we have discussed what is known about the articulatory positions of pharyngeal consonants, pharyngealized consonants, pharyngealized vowels and [±ATR] vowels. Production of pharyngeal and pharyngealized segments may involve retraction of the tongue root, retraction of the rear dorsum, sphincteric narrowing of the walls of the pharynx, retraction of the epiglottis, and elevation of the structures of the larynx. The tongue profile may be low, as in the pharyngealized vowels of !Xóõ, or two-humped, with a secondary stricture near the palate and deep sulcalization in between the two humps, as in Udi, or somewhere in between, as in Tunisian Arabic. Location of the stricture in primary pharyngeals and secondary pharyngealized segments varies from below the tip of the uvula to below the pocket of the epiglottis.

1.3.0 The present study

Although there have been a number of articulatory studies of segments with pharyngeal constrictions (Ladefoged, 1964, Lindau, 1979, Jackson, 1988a,b on Niger-Kordofanian languages; Jakobson, 1978 on a Nilo-Saharan language; Ali, 1970, Delattre, 1971, Ali & Daniloff, 1972, Ghazeli, 1977, etc. on Arabic; Traill, 1985 on the Khoisan language !Xóõ), most focus on a single language or type of segment; none undertook a cross-linguistic study comparing these different segments. Furthermore, their descriptions of stricture locations and mechanisms first of all vary considerably, and secondly, often focus on certain things to the exclusion of others. For instance, the position of the larynx is mentioned in only a few studies, but we know from Lindau (1979) and Jackson (1988) that this is important at least for [ATR] vowels.

For a typology of pharyngeal articulations which could provide the basis for the organization of features, one needs to know what is characteristic of each language and what traits are held in common by different languages. We need to be able to compare different segment types. For instance, are primary and secondary pharyngeal constrictions similar? There is little data that compares production in different languages. Can we compare [-ATR] vowels to pharyngealized vowels in Arabic, or even to pharyngeal consonants in Arabic? How do these compare with the two kinds of pharyngealization found in !Xóõ?

Phonological proposals also need to be evaluated by a wide range of data. Most of the proposals discussed in §1.1 only provide for one place of articulation in the pharynx. The exception is Ladefoged & Maddieson (1996), who provide two places. However, they do not resolve the problem of how best to analyze Xóõ vowels in terms of features. Are two places enough, or are more distinctions needed? There are other variables to be considered in a feature proposal. Is the way in which a pharyngeal articulation is formed predictable by its location, or is there a variety of options that must be accounted for?

There is clearly a need for better articulatory description and for better phonological interpretation. There are descriptive variations in items which are phonetically and phonologically labeled as the 'same' segment. These variations are certainly important in a complete description of a given language, but we do not as yet know how important these differences are in phonological terms. As Jackson (1988a) points out, we want to isolate gestures that appear to be independent cross-linguistically from those which are functionally associated in a given language. In the pharynx, these different components could include movement of the tongue root, rear dorsum, epiglottis, aryepiglottal muscles and folds, larynx and pharyngeal wall separately or in tandem.

In this dissertation we will undertake a cross-linguistic study in order to determine the basic gestures used in forming pharyngeal articulations in four different languages utilizing new tracings made from cineradiographic films where possible and published tracings of measurable quality. Factor analysis of tongue and vocal tract shapes (using PARAFAC) will be used to determine basic patterns of articulation in the pharynx. Cross-linguistic comparison will be carried out via a technique used in Jackson (1988a) in which data matrices are converted to covariance matrices and then analyzed in PARAFAC. At the end we will be able to say which segment types are similar to each other and use similar gestures; for example, whether the [-ATR] vowels of Akan are similar to the pharyngealized vowels of either Arabic or !Xóõ.

1.3.1 Organization of the study

The study is organized as follows. In Chapter 1 we have surveyed what is known about the production of different articulations in the pharynx and have discussed some of the feature systems used to represent them. Chapter 2 provides working definitions and illustrations of the structures and muscles which are involved in making pharyngeal articulations. Chapter 3 discusses methodology: tracing of x-ray films, measurement of tongue, larynx and pharyngeal wall positions in tracings, and use of PARAFAC to analyze the data. Chapters 4, 5, and 6 discuss analyses of data from Akan, Arabic, and Ndut and !Xóõ (the latter two languages are analyzed together), using PARAFAC to construct models of movement for individual languages. In Chapter 7, data from these four languages is pooled, converted into covariance matrices, and again analyzed through PARAFAC in order to make more direct comparisons between the languages used in this study. The patterns or factors derived from the pooled data set are fit to the individual language data sets to determine which best represent the data for each language. We will also discuss which factors model which segment types. These analyses allow us to say which segment types are similar or dissimilar, how the segments are formed, and where the constrictions are made. In Chapter 8, we first discuss the phonetic conclusions and the model of pharyngeal articulations which have been derived from PARAFAC analyses. These are then re-examined in light of the phonologies of the languages involved in this study to evaluate representation of pharyngeal segments by features.

CHAPTER 2 ANATOMICAL AND PHYSIOLOGICAL BACKGROUND

2.0 Overview

The following chapter provides working definitions and illustrations of the structures and muscles which are involved in making pharyngeal articulations. It also attempts to provide data on the relative dependence or independence of these structures. We will be primarily concerned with the root of the tongue, the epiglottis, the pharynx, and the larynx. As volumes could be written on some of these subjects, e.g. the larynx, the discussion will be limited to a brief description of the ways and means by which each is involved in pharyngeal articulations. The illustrations are my own, and were drawn with reference to figures found in the following sources: Bateman & Mason (1984), Berkovitz & Moxham (1988), Catford (1977), Dickson & Maue (1970), Dickson & Maue-Dickson (1982), Fried (1980), Grant (1962), Hardcastle (1976), Smith (1971) and Zemlin (1988).

The vocal tract can be divided into the oral cavity and the pharynx (See (2-1).) The boundary between the two is the palatoglossal arch, also called the anterior faucial[1] pillars, which is just anterior to the uvula. The pharynx can be further subdivided into the nasopharynx (which we will not be discussing), the oropharynx and the laryngopharynx. The oropharynx extends from the soft palate to the hyoid bone, while the laryngopharynx extends from the hyoid bone to the lower border of the cricoid cartilage (Hardcastle 1976:288, Zemlin 1988:223).

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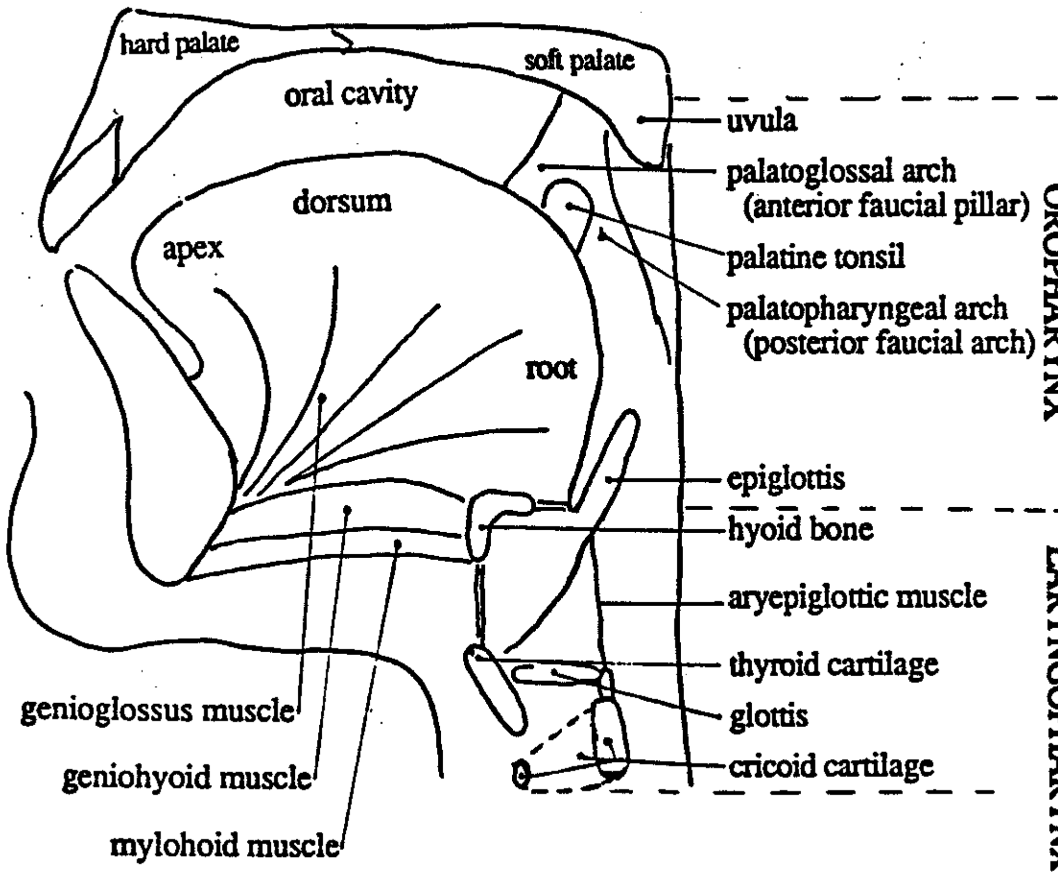
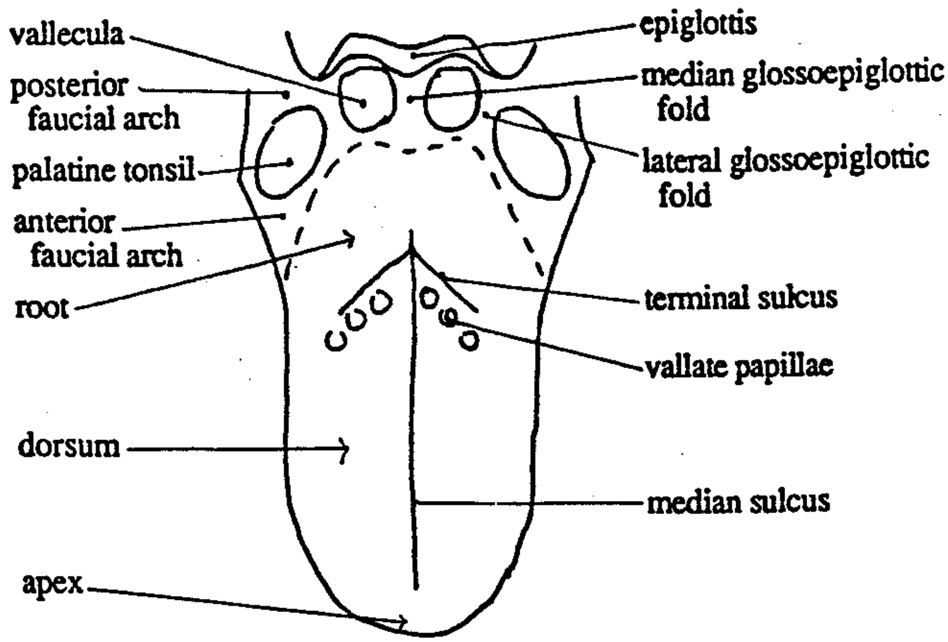
[1] Zemlin (1988) uses the spelling faucial, but it is also spelled faucal.

2.1 Tongue root

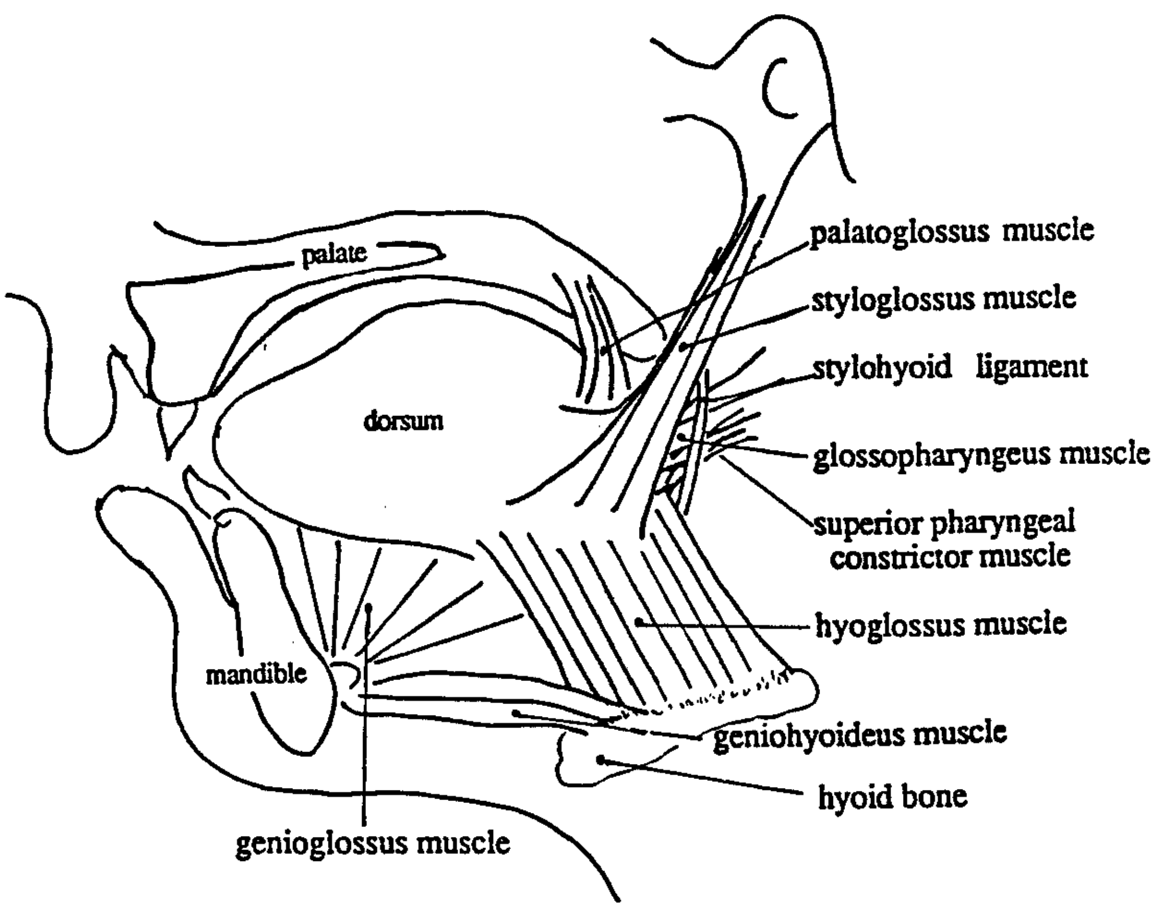
What is the root of the tongue? Linguistic texts seldom give a precise definition of where the dorsum ends and the root of the tongue begins, but refer to the root of the tongue as the posterior third which retracts into the pharynx to form a pharyngeal articulation. The 'posterior third' is a working term, but is not precise. There is no intrinsic muscle of the tongue which neatly corresponds to this posterior third, but there are several other criteria that can help us determine where the root begins. Among the few linguists who do give precise anatomical definitions, two different points of division are used: the tip of the epiglottis (Catford 1977:143-4) and the terminal sulcus (Smith 1971:8, Hardcastle 1976:91). The terminal sulcus is a v-shaped line of large, round papillae (buds), the remains of the thyroglossal duct. (See (2-2).) The tip of the epiglottis is somewhat lower than the terminal sulcus. The terminus sulcus is preferable as a dividing point for two reasons. First, it "demarcates the developmentally different, posterior one-third of the tongue from the anterior two-thirds" (Grant 1983:7-85). Second and more importantly, it is from this point down that the movement of the tongue becomes fully constrained by certain extrinsic muscles attaching to the lateral edges of the tongue, such as the glossopharyngeal muscle which is active in pharyngeal articulations. In contrast, there are no attachments to the lateral edges of the portion of the tongue anterior to the terminal sulcus. This second argument provides a stronger, more explanatory motivation for selecting the terminus sulcus over the tip of the epiglottis as the actual dividing point, although our definition becomes largely functional: the posterior third of the tongue is marked by having external attachments to the lateral edges and it is these attachments that will greatly determine the way the tongue moves in the pharynx. However, in practice, when working with x-rays, we will be forced to rely on the tip of the epiglottis as an approximation.



(2-1) Sagittal view of the vocal tract showing division into oropharynx and laryngopharynx.



(2-2) Diagram of the tongue showing the terminal sulcus, dorsum and root.



(2-3) Extrinsic muscles of the tongue.

Inferiorly, the tongue is anchored by the hyoglossus and genioglossus muscles (See (2-1) and 2-3).) The mylohyoid serves as the base or floor of the anterior portion of the tongue. In addition, the palatoglossus muscle (anterior faucial pillar) attaches the root of the tongue to the palate (Fried 1980:276) and the styloglossus muscle attaches the root of the tongue to the styloid process.

Four extrinsic muscles are the major forces in the positioning of the root of the tongue: the posterior fibers of the genioglossus, the glossopharyngeus, the hyoglossus and the styloglossus. (See (2-3).) The genioglossus is a fan-shaped muscle with a forward attachment at the front of the mandible. The anterior fibers curve up towards the tip of the tongue, while the posterior fibers run towards the root of the tongue, some of which may interdigitate with those of the superior constrictor muscle (which forms part of the back wall of the pharynx; see 2-6). The medial fibers insert into tissue near the midline of the tongue from root to tip. The inferior fibers attach to the hyoid bone, and some of these fibers also insert into the root of the epiglottis (WPP 77:42, Hardcastle 1976:71). Contraction of the posterior fibers brings the "whole body of the tongue ... forward in the mouth" (Hardcastle 1976:97). It is a major way of enlarging the pharyngeal cavity.

The glossopharyngeal muscle consists of the inferior fibers of the superior pharyngeal constrictor (Smith 1971:14; WPP 77:66). These inferior fibers insert into the sides of the tongue near the terminus sulcus (Smith 1971:14) and posteriorly insert into the midline pharyngeal raphe (WPP 77:66). In an electromyographic study, Smith (1971:60) found that the glossopharyngeus muscle was active for consonants involving pharyngeal constriction and for low vowels in general.

The hyoglossus is a sheet-like muscle which originates from the greater horn and body of the hyoid bone. The anterior fibers are connected to the mucous membrane near the tip of the tongue. The posterior and medial fibers interdigitate with the styloglossus and other tongue muscles at the lateral edges of the root of the tongue. Contraction of the posterior fibers lowers and retracts the body of the tongue (Hardcastle 1976:100, Smith 1971:12, Zemlin 1988:253). It may work with the styloglossus in positioning the tongue body for the production of back vowels (Hardcastle 1976:100).

The styloglossus is a flat fan-shaped muscle which originates from the styloid process, a projection of the skull at the level of the ear. The lower part blends with the hyoglossus at the root of the tongue and the upper part attaches to the inferior portion of the anterior tongue (Hardcastle 1976:98, WPP 77:40, 42, 64). It raises and retracts the back of the tongue during velar stops and high back vowels. Smith (1971:65) found greater activity in this muscle for the retracted allophone of /k/ than for the advanced allophone. It should thus also be active in the production of uvular consonants.

The muscles positioning the hyoid bone, the suprahyoid and infrahyoid, also position the tongue. These are described in §2.4 (on the larynx) below.

2.2 Epiglottis

The epiglottis is a leaf-shaped cartilage which has attachments to the root of the tongue, the hyoid bone, the thyroid cartilage and the arytenoid cartilages. (See (2-4) and (2-5).) It is attached to the root of the tongue by the median glossoepiglottic fold and two lateral glossoepiglottic folds. The lateral folds are also partially attached to the lateral wall of the pharynx (Fried 1980:274, Zemlin 1988:106-7). Two pits, or valleculae, are found between the epiglottis and the tongue, one on either side of the median glossoepiglottic fold. The hyoepiglottic ligament extends from the anterior surface of the epiglottis at its widest portion to the body of the hyoid bone. Inferiorly, the narrow stem of the epiglottis is attached to the thyroid cartilage just below the thyroid notch. "The lower part of the step of the epiglottis is known as the tubercle; this produces slight convexity on the anterior wall of the vestibule just immediately above the thyroid notch" (Ardran & Kemp 1967:373). A sizable fat pad, extending from the hyoid bone to the level of the thyroid notch, separates the epiglottis from the hyoid bone and the thyroid cartilage. The superior edge of the quadrangular membrane, the aryepiglottic fold (which contains the aryepiglottic muscles), attaches to most of the lateral surface of the epiglottis in front and to the corniculate cartilages (the apexes of the arytenoid cartilages) in the rear. (The lower edge of the quadrangular membrane is the ventricular fold, in which is embedded the ventricular ligament.) Only the upper lateral edges and the superior edge of the epiglottis are free. The cunieform cartilages (seen externally as the the cunieform tubercles) are embedded in the aryepiglottic folds just anterior to the corniculate cartilages and help stiffen the aryepiglottic folds. The fibers of the aryepiglottic muscle are continuous with the oblique arytenoid muscle (the more superficial of the [inter -] arytenoid muscle[2]) (Zemlin 1988:114-5, Dickson & Maue 1970:96). The aryepiglottic folds form a sphincter-like aperture for the larynx. Contraction draws the sides together medially and helps depress the epiglottis.

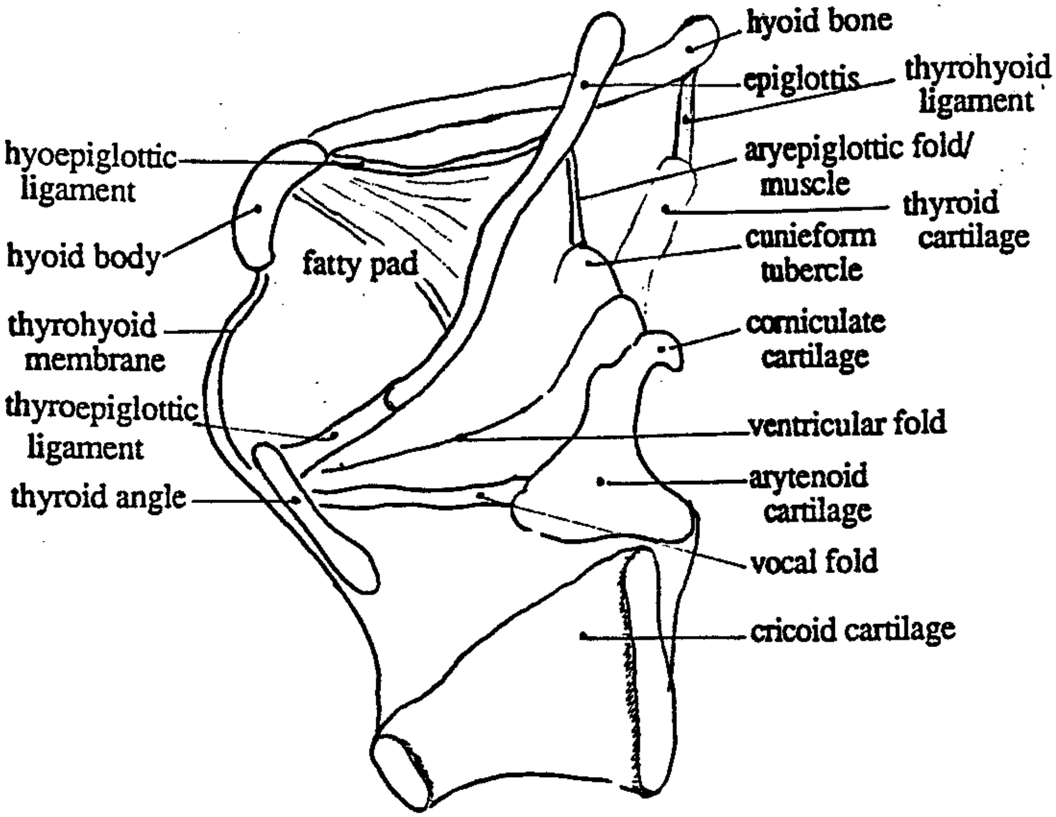
The main function of the human epiglottis is said to be to prevent food from entering the trachea during degluition (swallowing). The mechanism by which the epiglottis folds down over the opening of the larynx has been in debate: whether it is pushed by the tongue or whether it is pulled down by the aryepiglottic muscle. This question is important in a study of pharyngeal articulations because we want to know whether or not the epiglottis can move independently of the tongue root. Dr. John Bray of Cedars Sinai Medical Center, Los Angeles (p.c., 1990) says that movement backward is due to compression from the tongue root, and movement below the horizontal is due to a

[2]The prefix "inter-" is now usually dropped but is more descriptive.

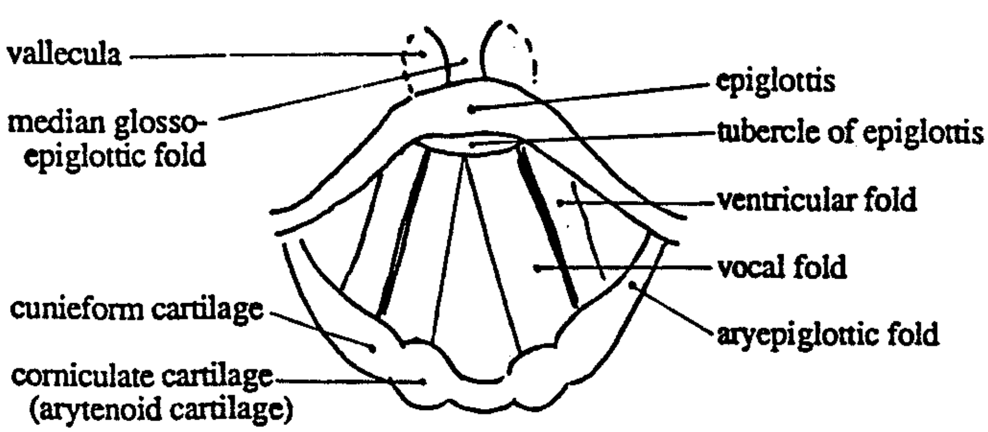
downward pull from the ary-aryepiglotticus (a term for the aryepiglotticus plus the oblique arytenoid muscles). The ary-aryepiglotticus is one of the intrinsic muscles of the larynx and is enervated through the recurrent laryngeal nerve. When there is palsy in the nerve, Dr. Bray found that the vocal cord is paralyzed and that the epiglottis is not pulled down. Thus there is evidence that when the tip of the epiglottis is extended away and down from the tongue root that this is being controlled independently of tongue root movement; where the tip is still relatively close to the root of the tongue it is probably moving passively. There is also the question of how much the aerodynamics of the vocal tract during speaking affect the position of the epiglottis, such that some retraction of the epiglottis away from the tongue root could be due to the Bernoulli effect.

2.3 Muscles of the pharynx

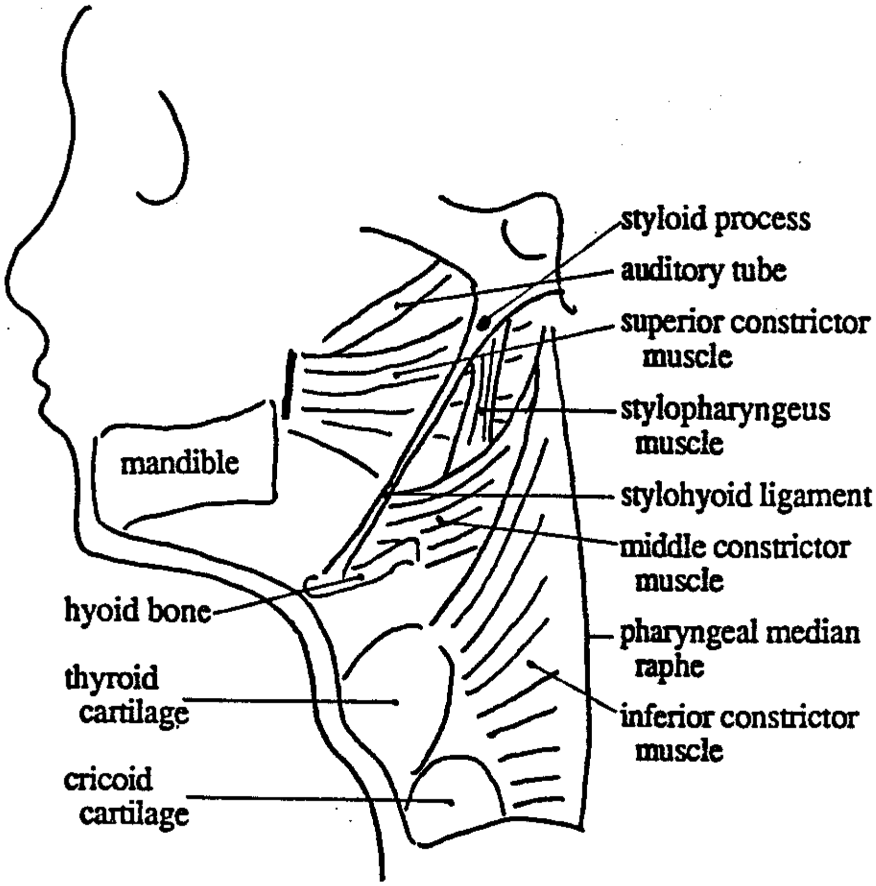
The pharynx is a musculomembranous tube suspended from the base of the skull (Zemlin 1988:223). It has no muscular attachments to the vertebrae. The pharynx is covered in back by three sphincter muscles: the superior constrictor muscle, the middle constrictor muscle and the inferior constrictor muscle. (See (2-6).) Their primary function is to narrow the pharyngeal tube in order to squeeze a bolus of food down into the esophagus. Two other muscles, the stylopharyngeus and the salpingopharyngeus, are longitudinal muscles which draw up the sides of the pharynx, which is important in swallowing. In addition, the palatopharyngeus, generally regarded primarily as a muscle of the soft palate, has longitudinal fibers running down the pharynx which can create constriction of the faucial pillars and elevation of the larynx. All of the above muscles are paired muscles: there is one on each side. Constriction of the oropharynx and length changes occur during speech and are important because they affect the resonant frequencies of the vocal tract. Below we will briefly describe these pharyngeal muscles.



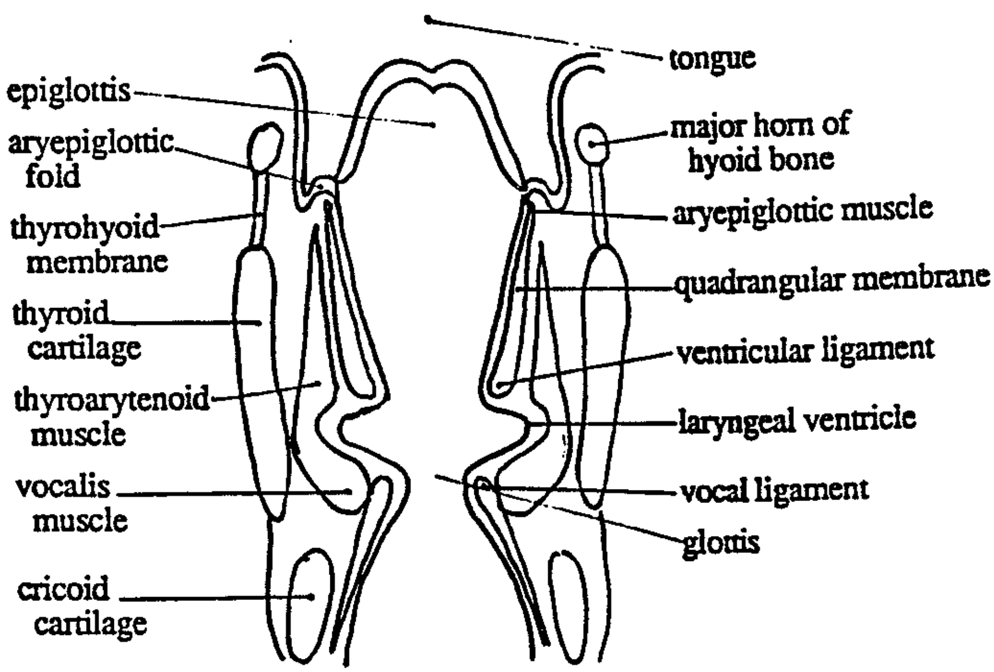
(2-4) Epiglottis and structure of the laryngopharynx.



(2-5) Interior view of larynx showing relation of epiglottis to vocal folds.



(2-6) Muscles of the pharynx.



(2-7) Coronal view of the larynx.

The superior constrictor is a thin quadrilateral muscle which covers the sides of the nasopharynx and part of the oropharynx. This muscle has several different origins and corresponding names (pteropharyngeus, buccopharyngeus, mylopharyngeus, and glossopharyngeus). The primary function of the superior constrictor is to narrow the upper wall of the pharynx. It would affect the area in which uvular consonants are made. As previously noted, the glossopharyngeus portion can also serve to retract the tongue.

The middle constrictor muscle is fan-shaped and covers most of the oropharynx. It has two origins: the hyoid bone, which also gives it a minor function as a larynx elevator, and the stylohyoid ligament. The fibers sweep back from these origins and attach to the median raphe. The lower fibers pass beneath the inferior pharyngeal constrictor and the upper fibers pass over part of the superior pharyngeal muscle. Due to its extensive coverage, it has the ability to constrict most of the oropharynx.

The inferior constrictor muscle originates along the sides of the laryngeal cartilages and is composed of two distinct parts. The upper fibers (the thyropharyngeus) sweep upward from their attachment at the thyroid cartilage to a level as high as the soft palate. The lower fibers (the cricopharyngeus), which arise from the cricoid cartilage and inferior cornu of the thyroid cartilage, are nearly horizontal and blend with the muscle fibers of the esophagus to form a sphincter. From a fixed larynx, the inferior constrictor can constrict the lower part of the pharynx and laryngopharynx, which in swallowing would help force the bolus down into the esophagus.

The stylopharyngeus muscle is a longitudinal muscle of the pharynx. It originates from the base of the styloid process and passes downward between the superior and middle constrictor muscles and inserts into the mucous lining of the pharynx and into the thyroid cartilage. As the styloid processes are about twice as far apart as the width of the pharynx, contraction of the stylopharyngeus widens the upper sides of the pharynx and raises the pharynx and the larynx (Zemlin 1988:275). Hyperelevation of the larynx seems to be important in swallowing to help close the vestibule to the larynx.

The salpingopharyngeus muscle is a minor longitudinal muscle of the pharynx, not always found in every individual. From its origin along the posterior lower border of the cartilage of the auditory tube, the fibers go directly downward, forming the salpingopharyngeal fold, directly adjacent to the palatopharyngeal arch (posterior faucial pillar), and blending with the palatopharyngeus muscle. It then inserts into the wall of the pharynx along with other muscle fibers at mid pharynx or lower levels. It draws the lateral walls of the pharynx upward and inward.

The palatopharyngeus arises in the soft palate and runs downward. It converges to form the posterior faucial pillar and then spreads out as it continues into the lower half of the pharynx. It inserts into the stylopharyngeus, the lateral walls of the pharynx, and the thyroid cartilage. When the soft palate is fixed, it can raise the thyroid cartilage or tilt it forward. Due to the semicircular course of fibers in the oropharynx, it can also act as a sphincter to decrease distance between the posterior faucial pillars in the upper pharynx (Zemlin 1988:266).

The lateral and posterior pharyngeal walls are constricted during swallowing, and movements of these walls also occur during speech. Much of the research on mesial displacements of the pharyngeal walls has focussed either on the area at the level of the velopharyngeal port or at the angle of the mandible, approximately four centimeters lower. Researchers have found differences in movement at the two locations. As velopharyngeal closure is effected by elevation of the velum and constriction of the lateral and posterior pharyngeal walls, greater mesial displacements occur for non-nasal sounds as compared to nasal ones at more superior levels of the pharynx (Iglesias et al.

1980:437). At the level of the angle of the mandible, a number of researchers have observed variations corresponding to different speech sounds. Using ultrasound, Kelsey et al. (1969) found greater displacement of the lateral pharyngeal wall for the low vowel /a/ than for the high vowel /i/ (in English). Minifie et al. (1970), also using ultrasound, observed outward movements of the lateral pharyngeal wall during the production of consonants, a lesser outward or slight inward movement for the high vowels /i, u/, and a substantial inward movement of 5 mm or more for the low vowels /æ,ɑ/. Zagzebski (1975) and Iglesias et al. (1980) also found similar patterns of differences between low and high vowels (the lowest level measured by Iglesias et al. is at the level of the lower tip of the (upper) maxillary incisors).

Magnitude of displacements vary according to site, speech sound and level. Iglesias et al. (1980) found posterior pharyngeal wall movement to be very small (0.0-4.0 mm), with the mean value for the lowest levels measured less than one millimeter, while lateral pharyngeal movements were quite large. Zagzebski (1975) and Iglesias et al. (1980) found greater overall movement at levels nearer the velopharyngeal port: Zagzebski recorded displacements of 8 mm., while Iglesias et al., using tomograghs and radiographs, recorded displacements of up to 16 mm. Measurements made by Iglesias et al. at their lowest level (the level of the lower tip of the (upper) maxillary incisors) had a mean of between ten and eleven millimeters for /æ,ɑ/ while Zagzebski recorded measurements of approximately 3.5 mm for /æ,ɑ/ at the level of the angle of the mandible. The differences in the magnitudes in these two studies may perhaps be a result of monitoring different sites or from inter-subject variability. In their study of twenty-five subjects, Iglesias et al. found that two of their subjects displayed relatively little movement.

Several muscles which constrict the upper oropharynx also play a role in velopharyngeal closure, thus we would expect to find a constricted upper oropharynx in non-nasal sounds. From anatomical and electromyographic evidence, Zagzebski and Iglesias et al. both believe that the superior constrictor muscle plays a major part in velopharyngeal closure. In addition, Iglesias et al. (1980:442) found a correlation between velar and lateral pharyngeal movement for six of their twenty-five subjects, suggesting that the levator veli palatini is important for a subset of individuals.

At the level of the angle of the mandible, both sets of authors suggest that the palatopharyngeus muscle is principally responsible for inward movements of the lateral pharyngeal walls. Zagzebski (1975:317) cites Podvinek's (1952) and Bosma & Fletcher's (1962) description of the contraction of the palatopharyngeus muscle as such that it would cause adduction of the posterior faucial pillars and mesial movement of the lateral pharyngeal walls. Electromyographic data from this muscle provided by Fritzell (1969) indicate that palatopharyngeus activity is not highly correlated with velopharyngeal closure but does coincide with productions of the vowel /a/ (Zagzebski 1975:317). Iglesias et al. (1980:443) suggest that the only muscle which would be able to widen the pharynx relative to rest position is the stylopharyngeus muscle. As mentioned above, it would raise the larynx as the pharynx was widened.

Several researchers have considered the influence of other structures, such as the hyoid bone and the mandible, on the movements of the pharyngeal wall. Iglesias et al. (ibid) cite data by Menon & Shearer (1971) which shows that the hyoid bone is positioned differently for the high vowels /i, u/ than for the low vowel /a/. Position of the hyoid bone relative to other structures has been shown to be important in swallowing (which will be discussed below) and may be important in pharyngeal configuration. Minifie et al. (1970) used bite blocks to examine the relationship between degree of jaw opening and displacement of the lateral pharyngeal wall. They found that lateral pharyngeal wall displacement (at the level of the angle of the mandible) increased as bite block size increased; that is the pharynx was narrowed as the jaw opening increased. However, during speech, they found that "active muscle constrictions during utterance appeared to deform the LPW [lateral pharyngeal wall] in about the same manner, with and without the bite block inserted" (Minifie et al. 1970:591).

So far we have only considered displacements of the pharyngeal walls in the upper oropharynx. There is less quantitative data on lower portions of the oropharynx. Many studies take measurements of pharyngeal width in such a way that there is no information on displacements of the pharyngeal wall. For instance, Perkell (1969) made extensive measurements of frame-by-frame tracings from cineradiographic film of thirteen nonsense words produced by a speaker of English. Although Perkell measures pharyngeal width at two places between the velum and the tip of the epiglottis, measurements are made between the cervical vertebrae C_2 and C_3 and the tongue dorsum, so there is no information about displacements of the pharyngeal wall. There are more studies which focus on the relationship between enlargement of the pharyngeal cavity and stop consonant voicing, e.g. Westbury (1983), but dilation of the pharynx at lower levels is primarily due to forward movement of the tongue root and attached structures. Catford (1977:75) explains that some of the forward movement may be partially due to downward movement of the larynx, which in turn may cause the hyoid bone to swing forward as it is pulled down and bring other structures forward with it.

We would expect to find movements which constrict the pharynx at lower levels. Jackson (1988a) took seven measurements along the dorsal wall of the pharynx from the larynx to the velopharyngeal port for his PARAFAC analyses of vowels of six languages (Akan, Chinese, French, Icelandic, Spanish and Swedish). The actual measurements are not published, but one can observe substantial movements of the dorsal wall in the articulatory factors generated by his cross-language covariance analysis.

Some correlations between different muscles and structures have been described above. Some of these include: constriction of the upper oropharynx and larynx-raising (if due to the stylopharyngeus), constricted upper oropharynx in non-nasal sounds relative to nasal sounds, narrowing of the pharynx as the jaw opens, especially for the vowel /a/, and front-back expansion of the lower pharynx as the larynx is lowered. We will see in later chapters the extent to which these occur in the languages investigated.

2.4 Laryngopharynx and larynx

The upper boundary of the laryngopharynx (2-1) is usually considered to be the hyoid bone (Zemlin 1988:223), which is roughly at the level of the pocket of the epiglottis. It is continuous with the esophagus below, and we will only consider the area extending to the bottom of the larynx, i.e. the bottom of the cricoid cartilage. The larynx opens to the laryngopharynx through the inlet or aditus to the larynx. The aditus laryngis is bounded by the epiglottis in front, the arytenoid cartilages and interarytenoid fold in the rear, and the aryepiglottic folds on the sides (Grant 1983:fig. 9-75).

There are nine cartilages which form the framework of the larynx, of which the main cartilages are the cricoid, the thyroid and the paired arytenoid cartilages. (See (2-4).) The others are the epiglottis, the paired corniculate and the paired cunieform cartilages. The ring-like cricoid cartilage sits just above the trachea. It is taller in the back than in the front. Just above the cricoid is the thyroid cartilage, composed of two thin sheets or lamina joined at the front to form the Adam's apple. At the rear of each lamina are two projections, one upward and one downward, called the superior and inferior thyroid horns (cornua). The inferior thyroid horns form part of the joint with the cricoid cartilage, while the superior ones are connected by the lateral hyothyroid ligaments to the hyoid bone. The paired arytenoid cartilages are located on the upper rear portion of the cricoid cartilage. The tips of the arytenoid cartilages are capped by the corniculate cartilages. The aryepiglottic folds attach to the corniculate cartilages in the rear and to the epiglottis in front. The cunieform cartilages are embedded in the aryepiglottic folds and stiffen them. The epiglottis is attached to the thyroid cartilage by the thyroepiglottic ligament, to the tongue by the lateral and median glossoepiglottic folds, and to the hyoid bone by the hyoepiglottic ligament.

Sawashima & Hirose (1980:31) have observed there are four basic types of laryngeal adjustments: abduction/adduction of the vocal folds, constriction of the false vocal folds and other supraglottic laryngeal structures, changes in the length and thickness of the vocal fold, and vertical movements of the larynx. In this section, we are mainly concerned with gestures which affect the length and width of the laryngopharynx, which would include the second and fourth types of laryngeal adjustments above, along with movements of the epiglottis and pharyngeal walls. We are very interested in gestures which are often linked together, although research in this area is not conclusive.

In our discussion below, we will first briefly describe the muscles which control vertical position of the larynx: the extrinsic laryngeal muscles, the suprahyoid and infrahyoid muscles, and we will consider their relationships with muscles which control the position of the tongue and pharynx. Next, we will describe what is known about the supraglottic laryngeal structures and their use in speech. Finally, we will describe how different structures of the laryngopharynx interact during swallowing.

The extrinsic laryngeal muscles are the sternothyroid muscles, the thyrohyoid muscles, and the inferior pharyngeal constrictor. The sternothyroid, located in the anterior neck, runs from the sternum to the the face of the thyroid cartilage, although some of its fibers continue upward and become part of the thyrohyoid muscle, while others continue into the inferior constrictor muscle. Its principal action is said to be to draw the thyroid cartilage down (Zemlin 1988:120). The thyrohyoid muscle is attached to the thyroid lamina at the same place as the sternothyroid, and runs upward to the lower border of the greater horn of the hyoid bone. Depending on whether the hyoid bone or the thyroid cartilage is fixed in position, it either raises the thyroid cartilage or lowers the hyoid bone. The inferior constrictor has already been described above; it has attachments to both the cricoid and thyroid cartilages. If the larynx is fixed, it can constrict the laryngopharynx.

The larynx is supported by its attachments to the hyoid bone. It is suspended by the hyothyroid membrane, which contains the middle and lateral hyothyroid ligaments, and is also connected by the thyrohyoid muscle mentioned above. As a result, other muscles which have an attachment to the hyoid bone can influence the position of the larynx. These are divided into two groups: those above the hyoid bone (suprahyoid) and those below (infrahyoid). The suprahyoid muscles are classified as laryngeal elevators (along with the thyrohyoid). They are the digastric, the stylohyoid, the mylohyoid, the geniohyoid, the hyoglossus, and the genioglossus. It should be noted that these muscles have other functions in addition to raising the larynx: contractions of the geniohyoid, the anterior belly of the digastric and the mylohyoid also open the mandible as well as raise the larynx (Perkell, 1969:63). Contraction of the following four muscles draws the hyoid up and forward: the anterior belly of the digastric muscle, the mylohyoid, the geniohyoid, and the genioglossus, while contraction of the posterior belly of the digastric and the stylohyoid draws the hyoid up and backward. The fibers of the hyoglossus run directly above and may also help elevate the hyoid bone. Both of the infrahyoid muscles, the sternohyoid and the omohyoid, are classified as laryngeal depressors along with the sternothyroid described above. The sternohyoid is anterior to the omohyoid.

Hardcastle (1976:69) mentions two uses of larynx raising:

"This elevation of the larynx is undoubtedly important in the second stage of swallowing to push the epiglottis up against the tongue and so help to prevent food entering the larynx. Raising of the larynx is also one way of decreasing the volume of the supra-glottal cavity and so increasing supra-glottal pressure."

He notes that larynx raising and the concomitant increase in supra-glottal pressure is important in the production of ejectives and in the production of voiceless stops to prevent the vocal cords from vibrating. Other uses of larynx raising are to raise the first formant (by shortening the vocal tract) and to raise pitch.

Changes in larynx height have been observed to occur for different segments, in particular for voiced consonants, and for changes in fundamental frequency. Fundamental frequency can also be changed using the intrinsic laryngeal muscles, the vocalis and the cricothyroid. As the intrinsic laryngeal muscles do not affect larynx height, we will not discuss these here.

From the effects of muscles which open the mandible to raise the larynx, we would expect to find a tendency for open vowels to have higher larynx positions. We would also expect voiceless consonants to have higher larynx positions to prevent vocal fold vibrations and voiced consonants to have lower larynx positions in order to maintain voicing. As we will see below, this is not always the case.

Ewan & Krones (1974) simultaneously measured vertical larynx position (using the thyroumbrometer) and fundamental frequency for VCV sequences in four languages in order to investigate vertical larynx position during stop consonants and vowels. In general they found that mean larynx height was higher for voiceless stop consonants than for voiced ones, although in English, for example, the ranges for voiced and voiceless consonants overlap and sometimes the relationship is reversed (as when speaker JD produced a mean of 3.9 for the syllable /du/ and 3.5 for /tu/). For the English and French speakers, /i/ has a higher mean larynx position than /a/, and /a/ has a higher position than /u/. However, the mean larynx position for /a/ was higher than /i/ for the Thai speaker. In contrast to the findings of Ewan & Krones, Perkell (1969:40) found vertical movement of the larynx to be highest for /æ/, followed by /a, i, ɪ, ɛ, ʊ, u/ for one speaker of American English. For /æ, ɑ, ɛ/, he also found that the hyoid bone and mandible were closer together, the geniohyoid was contracted, the mandible lowered, lips retracted, and the larynx raised; thus it would appear that these structures and muscles are operating as a unit to shorten the vocal tract and raise F_1 (Perkell 1969:40-41). Lindau (1975:56) showed that Umuchu Igbo /a/ has a higher larynx position than /i/, similar to the Thai speaker, but different than the English and French speakers. Lindau (1975, 1979) showed that four speakers of Akan consistently raise the larynx for [-ATR] vowels /ɪ, ɛ, ɔ, ʊ/ (/ʊ/ is usually the highest) and lower it for [+ATR] vowels /i, e, o, u/ (/u/ is usually the lowest).

Riordan's (1980) study of larynx height (using the thyroumbrometer) during English stop consonants casts doubt on the theory that the larynx is lowered during voiced stops to maintain voicing. She found that although the larynx was generally lower for /b/ than for /p/, the larynx lowered for both consonants produced in /i/ and /u/ contexts (and was lower for /p/ than /b/ in the /u/ context). More importantly, she found mean larynx lowering for /b/ to be less than 0.15 cm., less than would be needed to sustain voicing for any appreciable length of time.

Westbury (1983) measured larynx height from cinefluorographic tracings and observed the larynx to be generally highest during velar consonants, intermediate during alveolars, and lowest during labials. Although he found a tendency for the larynx to be lower during voiced consonants than voiceless ones, "such movements were neither characteristic of nor unique to the closures of those segments in all phonetic environments" (Westbury, 1983:1327). The reason is that an increase in cavity volume need not rely on larynx lowering alone and in fact does not. For instance, Westbury found the tongue root to move forward during the entire closure of medial /d/ and /g/. Westbury (1983:1335) notes that "*when* volume increases occur during voiced closures, how large they are, and how they are generated, vary widely across both place of articulation and phonetic environment."

Catford (1977:75) found that front-back expansion of the pharynx at a level just above the larynx (about 48 mm below the tip of the epiglottis) was accompanied by lowering of the larynx in the segments [bː, dː, gː, ɓ, ɗ, ɠ], as measured from cine-x-ray films. He hypothesizes that the front-back expansion of the pharynx is "due in part simply to the downward movement of the larynx: as the hyoid bone, to which the larynx is attached, is pulled downwards it tends to swing forward, as a result of the way it is suspended from structures above and in front" (Ibid.).

Ewan & Krones (1974), Riordan (1980) and Westbury (1983) have shown that there is variation among speakers of American English in lowering of the larynx during production of voiced stop consonants. Westbury (1983) has demonstrated that he sometimes uses other mechanisms to enlarge cavity volume. Perkell (1969), Ewan & Krones (1974), Lindau (1975, 1979) and Westbury (1983) have shown that vertical larynx height corresponds with different segments in different languages, and sometimes within the same language. Lindau's four Akan subjects seem to be more uniform than speakers of English. Only a small number of muscles have been monitored, and even these few also show variation. As movement of one structure may affect another, we have been on the lookout to see when these associated movements are utilized in speech. While there are some instances corresponding to predictions, there are also many cases which do not.

The epiglottis, laryngopharynx and larynx are put to vigorous use during swallowing. Watching x-ray films of swallowing, one is struck by how sudden and violent the movements appear. The tongue of the epiglottis is turned downwards in a very rapid gesture (Ardran & Kemp, 1977, say it is within 1/25 of a second) and bent downwards at each side over the larynx. The larynx itself is raised and the uppermost portion of the superior horns of the thyroid cartilage may pass through the arch formed by the greater horns of the hyoid bone (Ardran & Kemp, 1977:374). The lower part of the epiglottis (the tubercle) bulges backwards as a result of the approximation of the thyroid cartilage and the hyoid bone while the arytenoid cartilages are tilted forward, so that the dorsal surface of the epiglottis is brought into contact with the corniculate cartilages and seals the glottis. This type of closure between the tubercle of the epiglottis and the arytenoid and cunieform cartilages will be termed aryepiglottic closure. The aryepiglottic sphincter muscles, i.e. the aryepiglottic muscles within the aryepiglottic folds, and the oblique arytenoid, the thyroepiglottic and the external thyroarytenoid muscles, are involved in this closure (Lindqvist, 1972). Some of the gestures used in swallowing may be used in speech. Earlier we discussed larynx raising. Most sources do not document whether the tubercle of the epiglottis bulges backward in larynx-raising, although Catford observed the obverse case: front-back expansion of the aryepiglottic area when the larynx is lowered.

Lindqvist (1969) suggests that aryepiglottic closure may be utilized in speech. Lindqvist's (1969) pictures of a phonetician's glottal stop taken through a fiberoptic laryngoscope show aryepiglottic closure. Lindqvist (1969:30) and Sawashima & Hirose

(1980) found that the aryepiglottic sphincter can also be used in creaky voice and in whisper. Catford (1977:105) believes that ventricular stops and aryepiglottic closure are in reality the same. Catford (Ibid.) describes ventricular stops in which the ventricular bands are brought together by intense constriction of the upper larynx. He states that ventricular stops are usually accompanied by closure of the vocal folds. This ventricular plus glottal stop [ʕʔ] is found in several north Caucasian Nakh languages, such as Chechen, Ingush and Batsbiy, and in Tigrinya, and contrasts with ordinary glottal stop in these languages (Ibid.). Catford (1977:163) describes another ventricular sound, a breathy-voiced ventricular fricative trill found in some of the north-west Caucasian Abkhazo-Adyghe languages. Catford points out that a simple glottal stop does not affect the quality of neighboring vowels, while a ventricular stop "imparts a noticeable 'strangulated' nuance of pharyngealization to preceding and following vowels" (Ibid.).

Above we have mentioned that some of the muscles which open the mandible can also raise the larynx, unless the larynx is fixed in position. We would also expect to find front-back expansion of the laryngopharynx as the larynx is lowered. From our survey of pharyngeal articulations in Chapter 1, we know that we can expect constriction of the laryngopharynx in !Xóõ strident vowels and Arabic pharyngeals. How similar are the two sets in laryngopharyngeal constriction? What other segments characteristically display constriction of the laryngopharynx? These are a few of the questions we will pursue in subsequent chapters.

2.5 Summary of the chapter

We tend to think of segments as discrete units; spectrograms reveal how blurred the edges are and cineradiographic films seem to show almost continual motion by all components of the vocal tract: lips, tongue, jaw, velum, pharyngeal walls and larynx. Different muscles and structures are multiply interconnected, and there are numerous possible actions and many possible degrees of movement. An action to move one structure may result in correlated movements elsewhere, depending on what structures are being held in a fixed position at a given time and which are allowed to move. Our survey of anatomy may sound a bit like the old song "the hip bone is connected to the thigh bone and the thigh bone is connected to the knee bone" etc. But due to all the interconnectedness there are constraints which we must discover; there are also gestures which tend to go together as in swallowing and it is natural to think these coordinated gestures may be co-opted for speech. We will be looking for articulatory prototypes: those articulatory gestures which best represent a given segment. We are looking for the gestures which are most essential for producing a given segment, and we may find that there is a menu of options, as Westbury found for ways to expand the cavity for maintaining voicing for English stops.

CHAPTER 3 METHODOLOGY

3.0 Introduction

In this chapter we will discuss the sources, equipment, and methodology used to trace x-rays and to measure and analyze the x-ray tracings. There is a large quantity of data available either through published x-ray tracings or x-ray films which are still extant. X-ray films have an advantage over other sources of articulatory data in that the pharyngeal area can be seen and thus investigated. This is not possible with systems such as the microbeam which rely on fixing pellets to the tongue, as pellets cannot be securely affixed to the tongue root. Given this body of extant x-ray materials, it was decided to utilize them to try and resolve some of the descriptive questions raised about pharyngeal segments in Chapter 1. Lindau (1979) used a limited number of measurements and statistical techniques to investigate Akan. And while that gave us a great deal of information on the [ATR] contrast in Akan, it is difficult to create a model of articulatory movements with a limited number of measurements. Once the number of measurements is increased, a way needs to be found to extract dimensionality from over-rich data. One main way to do this is to use factor analysis or principal components analysis. Jackson (1988a) discusses in some detail how this method can be applied to physiological data.

3.1 Language data

I have compiled data on pharyngeal articulations using the collection of x-ray films and published tracings in the UCLA Phonetics Lab X-ray File. These sources are listed in (3-1). Although pharyngeals and pharyngealized segments occur in nine language families, I was only able to obtain potentially useable x-rays from four families: Afro-

Asiatic, Niger-Kordofanian, Khoisan, and Caucasian. Although there are x-rays of some Nilo-Saharan languages (Jacobson, 1978), the sets of x-rays published do not contain a full set of vowels. X-rays of Amerindian languages would have been very interesting, but none are available. Some sources listed in (3-1) were later eliminated, primarily because of distortions within a set of tracings for one speaker.

3.2 Tracing equipment

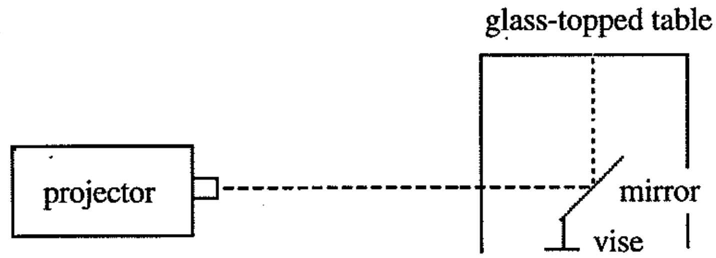
Tracings were made from a number of x-ray films, either because none existed or in order to supplement a set of existing tracings. The films from which tracings were made include Ghazali, Ferguson Abramson (1962), Traill, Ali, and Lindau (1972) (the latter were of two vowels to supplement her set of tracings on Akan). All films were converted to 16mm. format if they were not already, and were projected using a Lafayette Projector Data Analyzer (manufactured Jan. 1979) or a Lafayette Pony 16 Data Analyzer (model 00152, manufactured 1990). The projector was aimed at a front surface mirror (8 inches square) tilted at a 45 degree angle, directing the beam up to a glass-topped table. The glass was 1/4 inch thick clear glass. The projector set-up is illustrated in (3-2). The mirror was held by a vise and the angle was determined by taping strings with attached weights to both the top and bottom of the mirror and letting them fall plumb to the floor. The angle of the mirror was then adjusted so that the distance between the weights was approximately 5.66 inches (using Pythagoras' theorem to solve the lengths of the sides). (See (3-3).) Tracings were made on tracing paper placed on the glass. The frame counter was set to Ø at some identifiable frame, and the frame number was recorded for each frame traced.

(3-1) X-ray data sources

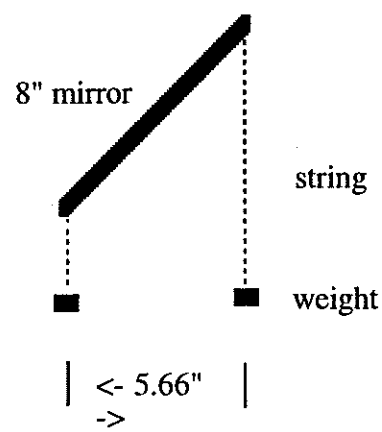
Language family	Language/ dialect	No. of speakers	Segments	Source
Afro-Asiatic/ Semitic	Arabic/ Iraqi	1	i a u t tˤ k q ħ ʕ	Al-Ani (1970)
Afro-Asiatic/ Semitic	Arabic/ Iraqi	3 1	no tracings pubd. t tˤ s sˤ k q a aˤ u	Ali & Daniloff (1972) Ali (no date)*
Afro-Asiatic/ Semitic	Arabic/ Iraqi	1	t tˤ d dˤ s sˤ zˤ q	Giannini & Pettorino (1982)
Afro-Asiatic/ Semitic	Arabic/ Moroccan/Classical	4	k χ q ɣ ħ ʕ h ʔ	Boff Dhkissi (1983)
Afro-Asiatic/ Semitic	Arabic/ Saudi/Classical	1	t tˤ k q æ a	Bonnot (1977)
Afro-Asiatic/ Semitic	Arabic/ Tunisian (Southern)	1	t tˤ s sˤ r rˤ ðˤðˤ x q x q χ ʁ ħ ʕ	Ghazeli (1977)
Afro-Asiatic/ Semitic	Arabic/ Tunisian (Southern)	1	t tˤ s sˤ zˤ r rˤ k g q χ ʁ ħ ʕ i iˤ æ aˤ u uˤ	Ghazali (no date)*
Afro-Asiatic/ Semitic	Arabic/ Tunisian (Tunis)	1	i ɪ ɛ æ a ɑ ʉ u	Metoui (1989)
Afro-Asiatic/ Semitic	Arabic/ Qatari	1	s sˤ ħ ʕ	Bukshaisha (1985)
Afro-Asiatic/ Semitic	Arabic/ Damascan	3	t tˤd dˤ s sˤ z zˤ r rˤ k g x χ ħ ʕ	Ferguson & Abramson (1962)*
Niger-Kordo-fanian/ Volta-Comoe	Akan	4 2	i ɪ e ɛ ɑ̃ ɔ o ʊ u ɑ̃	Lindau (1975/p.c.) Lindau (1972)*
Niger-Kordo-fanian/ West Atlantic	Ndut	1	i ɪ e ɛ ə ɑ ɔ ʊ u iː ɪː eː ɛː ɔː ɑː ɔː ʊː uː	Gueye (1986)
Khoisan	!Xóõ	2	i e a o u a̰ ʉ̰ a̰h ʉ̰h	Traill (1985); Traill (1972, 1975)*

NW Caucasian	Bzyb (Abkhaz)		χ χ͡ħ χ͡ħʷ s ʃ ʂ z zʷ ts tsʰ ʦ̡ ʦ̡ʰ	Bgažba (1964)
Dagestanian	Dargi Kebakh-Mulebkin, Khajdak & Urkarakh dialects (1 sp./dialect)	3	i e æ a o u ɨ b pʰ pː p' m t̜ʰ kʰ kː k' ʦ̜ʰ ʦ̜ː ʦ̜ tsʰ tsː ts' qχ v ẕ s̱ z s x χ χ' ħ ʕ ʜ ɾ ʀ ʀ̥	Gaprindašvili (1966)
NW Caucasian	Ubykh	1	s ʃ ʃʷç çʷ sˤ x xʲ χʷ ħʷ kʲ kʷ l l' rˤ	Leroy & Paris (1974)

*Tracings made from 16mm. films by Susan Hess



(3-2) Film tracing set-up.

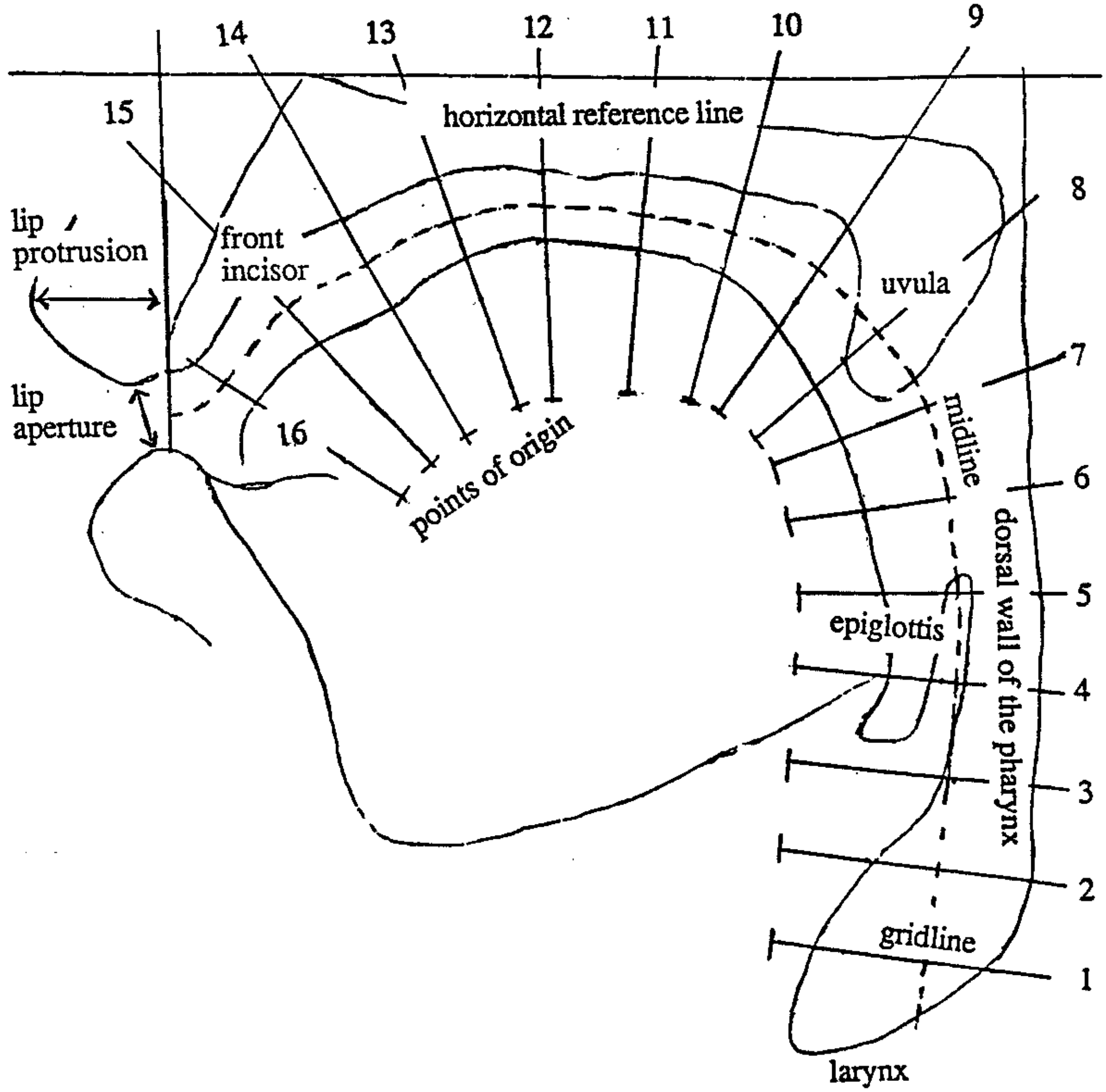


(3-3) Determination of the angle of the mirror.

3.3 Measurements

The data set consisted of measurements made from x-ray tracings of single frames which were selected at the peak of a gesture. In order to insure that measurements were taken of comparable structures for each speaker, measurement grids were constructed so as to be dependent on the individual's size and anatomy (also see Jackson 1988a). A completed measurement grid is shown in (3-4). The measurement grids were constructed as follows. First, a horizontal reference line fairly parallel to the superior surface of the palate was made. A perpendicular to the horizontal reference line was dropped through the apex of the front incisor. This marked the forward end of the measurement area. Next, a mid-line was drawn which would serve as reference for the sectioning of the vocal tract. Where possible, this was done by initially selecting a tracing of a vowel with the most uniform cross-sectional area along the length of the tube (usually a mid-low or low front vowel) and drawing a line in the sagittal plane midway between the tongue and the upper or back surfaces. In practice, it was found that the easiest way to ensure that the points to be joined in forming that midline were located on lines that intersect the tongue at ninety degrees was to use a piece of quad-ruled graph paper. Starting with the apex of the tongue, the tracing was placed on the graph paper so that the outline of the tongue was on top of a vertical line, which thus formed a tangent to the tongue. The distance between the tongue and palate was measured along an intersecting horizontal line on the graph paper and the midpoint marked on the tracing. The next point was measured along the next horizontal line, and the tracing was turned to ensure that the outline of the tongue at the next point was still vertical. This was continued all the way along the vocal tract to the larynx, and then all of the marked points were joined to form the mid-line. The vocal tract was then divided into sixteen sections, the first beginning at the larynx and the last ending at the incisors. To compensate for differences in pharynx length, these sections were not all of equal length but were tied to anatomical landmarks. The top edge of the third section was placed at the mean position of the pocket of the epiglottis, the center of the fourth intersected the epiglottis, and the center of the seventh was placed a few millimeters below the uvula. The position of gridline seven was lowered if its initial position would not have allowed gridline eight to intersect the upper pharyngeal wall approximately behind the middle of the uvula. The remaining sections were then distributed evenly between these fixed points. As the mid-line is curved, distances between fixed points were measured by placing thin colored wire (30 AWG Kynar wire) on the mid-line and marking the fixed points on it. The distances between the fixed points were then measured on the straightened wire. At the center of each section, a gridline was drawn perpendicular to the midline. Once again, this is most conveniently done by placing the tracing on quad-ruled graph paper. Measurements on each gridline were made from an arbitrary origin which was set as one centimeter (1.5 cm. for the Akan speaker) below the surface of the tongue on the tracing from which the midline was constructed.

For each segment and speaker, thirty measurements were made from the points of origin shown in (3-4): sixteen along the surface of the tongue, one of the epiglottis along gridline 4, eight of the rear wall of the pharynx along gridlines 1 through 8, two vertical measurements from the horizontal reference line, one each of larynx position and of the position of the pocket of the epiglottis, one of laryngopharyngeal width measured across the tops of the arytenoid cartilages (or widest point near gridline 2 if the arytenoid cartilages were not visible), one of lip protrusion from the vertical line dropped through the incisors to the most anterior lip position, and one of lip aperture taken by measuring the shortest distance between upper and lower lips. The two lip measurements are similar to two used by Jackson (1988a), which he found to be among the most useful.



(3-4) Measurement grid showing horizontal reference line, vertical line through the apex of the upper incisor, midline, gridlines, gridline points of origin, and measurement of lip protrusion and lip aperture.

The measurement system described above utilizes fixed grids, as indeed do all previous language studies utilizing PARAFAC. The placement of gridlines is based on one segment and is not adjusted for subsequent segments, during which the tongue, epiglottis and larynx may be moving up or down. We were concerned in particular that measurements of given points, particularly of the base and tongue of the epiglottis, were made on different gridlines at different times. Using the Akan data set of four speakers and nine vowels, a test was made to see if rescaling the gridlines for each segment (i.e. drawing a new grid which was tied to anatomical landmarks for each segment) would improve the fit of the solution. Gridline 8 was fixed as a 45-degree angle from the intersection of the horizontal reference line and a vertical line running through the rear wall of the pharynx. Sections 9 through 16 were divided as before. For each segment, the top edge of section 3 was placed so as to intersect the bottom of the epiglottal pocket. The first three sections equally divided the distance between the larynx position for that segment and the pocket of the epiglottis. Sections 4 through 7 were also placed so as to create sections of equal length between sections 3 and 8. In this way, the gridlines followed the tongue up or down in the different segments. However, the R^2 (explained in §3.4), or fit of the resulting three-factor solution was only .82, while a comparable three-factor solution without rescaling had a R^2 of .868. As the fit decreased rather than increased, this laborious method was not followed.

An additional test was done to determine the best way of measuring the rear wall of the pharynx. The method first described above measures the pharyngeal wall from the same gridline points of origin used in measuring the surface of the tongue. As this involves angled, non-perpendicular lines at the intersection with the pharyngeal wall, a different origin was used which allowed the measurement lines to be perpendicular to the wall. Using the vertical reference line dropped through the front incisors, measurements were made between the vertical reference line (see (3-4)) to the original gridline intercepts on the wall. A right-angle was used to make sure the measurement lines were perpendicular to the vertical reference line. Using the Akan data set again, measurements were made on all four speakers. The R^2 for a three-factor solution based on this new set of measurements was slightly higher: .887 vs. .868. However, as the increase was so small, it was felt that it did not warrant the additional effort in measurement.

3.4 PARAFAC

There are difficulties in comparing primary pharyngeal articulations with secondary ones, as one must compensate in the latter case for the fact that the tongue blade and body are involved in forming an anterior constriction, thus constraining the movement of the tongue root. One method which would be able to subtract out anterior tongue blade/body movement is factor analysis, as it separates the variance in the measurements that constitute a set of data into its major components. In effect, it constructs a model of underlying components (which are referred to as factors), which, in combination, make up the data set. In this case, each factor describes a type of underlying movement of the tongue and other structures; different segments are formed through combinations of varying amounts of factors. The program which was used, PARAFAC, has the advantage of supplying unique solutions and has been argued to supply empirically meaningful factors through intrinsic axis solutions (Harshman and Lundy 1984). It has also been well-tested on articulatory data (Harshman, Ladefoged and Goldstein 1977, Linker 1982, Lindau 1987, Jackson 1988a and 1988b).

The following description of PARAFAC relies heavily on Harshman, Ladefoged and Goldstein (1977), Linker (1982), Harshman and Lundy (1984a), Lundy and Harshman (1985) and Jackson (1988a,b). Terbeek and Harshman (1971) and Terbeek

(1977) also helped shape my understanding of PARAFAC. PARAFAC is a three-way factor analysis model developed by Richard Harshman in which a series of data matrices (a data array) rather than a single matrix (as in two-way factor analysis) is analyzed. "Ways" refers to the dimensions of the matrix or data array, e.g. across, down and back. The addition of the third "way" or dimension sufficiently constrains the procedure if certain assumptions are met so that only one solution is possible (this is called intrinsic axis rotation). This is not the case with two-way factor analysis, where multiple solutions are possible. PARAFAC utilizes an iterative procedure from random starting points, wherein each subsequent iteration re-estimates factor loadings and attempts to improve the fit of the underlying factors that are used to model the data. PARAFAC does not retain factors from one analysis to the next, but derives a new set of factors for each analysis.

In PARAFAC terminology, the "ways" or dimensions of a data array are called "Modes". In this application, the Mode A (across) input contains the vocal tract data, i.e. the thirty measurements previously described, for each Mode B (down) segment; Mode C (back) refers to a succession of such matrices, one for each speaker, and can be thought of as representing variations in vocal tract shape and articulatory patterns across speakers.

The output of PARAFAC consists of three matrices of factor loadings (weightings), one matrix for each mode of the data array. These matrices are organized as number of factors by number of levels in the given Mode (e.g. number of levels in Mode A = number of measurements/columns). In a three-factor solution, the first matrix will contain the loadings or the degree by which each of the three factors will generate a displacement for a given data point; the second matrix contains the segment loadings, that is the degree to which each of the three factors contributes to a segment; and the third matrix contains the speaker loadings, which reflect both the scale of the data and the degree to which a speaker makes use of each of the three factors. The order of factors in the output reflects their relative importance in the solution.

The basic PARAFAC equation is given below:

$$x_{ijk} = \sum_{r=1}^{q} (a_{ir}b_{jr}c_{kr}) + e_{ijk}$$

which can be expanded for our purposes as:

$$x_{ijk} = a_{i1}b_{j1}c_{k1} + a_{i2}b_{j2}c_{k2} + \ldots + a_{in}b_{jn}c_{kn} + e_{ijk}$$

where x_{ijk} is a point in the data array for tongue, pharyngeal wall, epiglottis, larynx or lip measure i for segment j as spoken by speaker k;

a, b, c are the loadings (weightings) for articulatory measure, segment, and speaker for factors 1 through n;

e is an error term.

The number of factors extracted is left to the judgment of the researcher, the goal being to select a stable solution that represents a global optimum. A typical procedure is to run a series of solutions from one or two factors up to six or more and select the best one in terms of the following criteria: convergence, uniqueness, adherence to the system variation assumption, relative amount of increase in the values of R^2 between solutions, parsimony, correlation between factors, and interpretability of factors. Convergence and uniqueness are the two basic criteria which must be met before a solution undergoes any further consideration. Convergence reflects the stability of a solution, and in this application meant that the amount of change in estimation of factor loadings from one iteration to the next was less than 0.1%. Uniqueness means that a global, rather than a local, optimum was found. In practice this means that several trials from different starting points yielded matching solutions.

After the two basic criteria of convergence and uniqueness are met, the remaining five criteria are used to select a best solution, i.e. optimum number of factors for the data set. Adherence to the system variation assumption is very important, as PARAFAC will only yield a unique solution if it is met. The addition of the third "way" will not adequately constrain the procedure by itself unless there is systematic variation between speakers, by which it is meant that speakers use varying amounts of the factors. If all speakers use the same amount, then no constraint is added to the equation; it is merely multiplied by a constant. Similarly, it is also not met if some speakers do not use certain factors at all or have inverse relationships to other speakers. Adherence to this assumption can be judged through inspection of the Mode C speaker loadings. R^2 measures the amount of variance accounted for by the PARAFAC model for a given number of factors, and thus the degree of fit between the model and the data. It can be used to help one judge the importance of additional factors in modelling the data: a large increase in R^2, e.g. in going from a three-factor solution to a four-factor solution, indicates that the additional factor significantly improves fit. Related to this criterion is the notion of parsimony. We look for a solution that models articulatory behavior with the fewest number of factors. Factor correlations (or the cross-products also supplied by the program) measure dependence or similarity of pairs of factors within each mode. Highly correlated or inversely correlated factors indicate problems with the data, such as speakers behaving in opposite ways, or that more factors were extracted than were actually present in the data, and such solutions tend to be uninterpretable. Finally, a solution must be interpretable. In this application we are looking for linguistically meaningful solutions which show the vocal tract and segments behaving in plausible ways.

Difficulties in running PARAFAC at various times have led to some empirical insights as to the types of things which affect it. As two of the /ɑ/ tokens in the Akan data set were traced at a later date and on different equipment, there was some question of how to scale the new tokens to match the original set. An initial fitting was made by matching the size of the incisors, lips and the broad outline of the vocal tract. Initial PARAFAC runs gave very unsatisfactory results: high correlations among the factors extracted and difficulty in assigning a linguistic interpretation to the factors. Three types of changes were made to try to improve the solution. The first was to rescale the vertical measures of epiglottis and larynx position, as these are much larger than the tongue and pharyngeal wall measures. Their larger size meant that they would in effect be weighted, and might contribute disproportionately to the solution. The epiglottis measure was halved and the larynx measure was divided by three. This rescaling did not lead to any improvement in the solution. Next, the epiglottis measure was removed entirely, as I was not completely sure it was moving in a consistent way. This made no difference in the patterns of factor loadings. Finally, the scale of the two new tracings was reduced by three percent. This gave solutions with low correlations between factors and clear-cut linguistic interpretation. A three percent difference for sixty points out of 1080, and in fact even for thirty out of 1080 (using only one /ɑ/ token with the wrong scale), when undergoing successive iterations, was sufficient to change the geometry of the solution. It is apparent that PARAFAC is very sensitive to distortions of scale within the data set for one speaker. Distortions in the speaker mode (mode C) affects the ability of the program to use the scale of each speaker in intrinsic axis rotation. With this in mind, x-ray tracings in which there appeared to be distortion in scale between one tracing and the next were eliminated. For instance, in Gaprindašvili (1966), distortions in the horizontal scale (if the incisors in two different tracings were matched, the positions of the velum and dorsal wall of the pharynx were impossibly far apart) prevented data from Dargi from being included in this study.

3.5 Missing Value Estimates

Missing data arose when a certain area could not be seen clearly on an x-ray film, when an area (usually the lower pharynx) was not traced in a published set of tracings, when a segment was missing from the inventory, when the larynx rose above the first gridline, or when the apex of the tongue was drawn back and did not intersect with the sixteenth gridline. PARAFAC provides two ways of handling missing data: through missing data codes or through a subscript table. With missing data codes, each point ("cell") with missing data was assigned a code, and the value was estimated entirely by the program. Upper and lower limits can be placed on the first estimate tried by the program, but it is free to ignore these limits on successive iterations. With a subscript table, the user supplies an initial estimate, entered with the rest of the data, and a subscript table identifies its location and status as a missing value estimate. The program then tries to improve on the initial estimate.

Both methods were tried on the Akan data set which had one missing /ɑ/ segment (thirty measurements) and a few odd missing data cells. When the missing value codes were used, it was found that the program often supplied absurdly large or small values for any given data cell, which bore no relation to the data points contiguous to it. The program essentially uses these missing data codes as wild cards, and will accept any number that will improve the fit of the overall solution. When estimates and a subscript table were supplied for the missing data cells, the program was constrained so that subsequent changes in the estimates were not very large. This procedure yielded two- and three- factor solutions which were almost identical to the two- and three-factor solutions presented later in the section on Akan in which actual data - measurements of a new tracing of the missing /a/ token - were used. So this procedure was continued for all cases of missing data.

3.6 Analyzing data with non-identical segment inventories

Use of PARAFAC in the manner described in §3.4 requires a minimum of three speakers, preferably more, with identical segment inventories. In the direct mode, the segment inventories must be the same, because the data matrices must be the same size - the same number of rows and columns in each matrix. Fewer segments or additional segments would result in a smaller or greater number of horizontal rows in the data matrix. Jackson (1988) demonstrated how a large, non-uniform data set can be analyzed through the use of covariance matrices. The initial data matrices of $N_{measures}$ by $N_{segments}$ for each speaker are converted into covariance matrices of $N_{measures}$ by $N_{measures}$. The non-uniform segment mode is eliminated, and its information is contained indirectly in the new covariance matrices. The data matrices are now all the same size, in our case, thirty columns by thirty rows, as there are thirty measurements. The output of a PARAFAC analysis using this technique consists of articulatory loadings and speaker loadings. Thus we can still plot the articulatory displacements (factors) which underlie a data set, and we can tell the degree to which each speaker uses a given factor. Jackson (1988) used this technique only in pooling together data from a large number of speakers and languages. We will use it this way also in Chapter 7, but we will also use it for a smaller data set, in order to include data from two languages. There is data for only one speaker of Ndut and data on only two speakers of !Xóõ. There are not enough speakers to analyze either language with PARAFAC directly, so we will use covariance matrices to analyze them together.

3.7 Summary

This chapter discusses x-ray sources, procedures used in tracing frames from cineradiographic film, measurement of tracings, and analysis of the measurements using PARAFAC. We have found, through experimentation, how missing values in the data sets should best be approached, and how to make measurements in the pharynx to give stable results within a PARAFAC analysis. We have discussed two methods of analysis within PATAFAC, one which uses direct measurements and one which uses covariance matrices. All the data presented in the following chapters will be analyzed with one or both of these techniques.

CHAPTER 4 AKAN

4.0 Introduction

There has been an ongoing debate on how best to represent the distinguishing feature found in African vowel harmony systems and what its relationship should be with other features. Currently the vowel harmony feature is usually referred to as [ATR], for [Advanced Tongue Root]. Lindau (1979) has compared use of the tongue root in Akan with that in pharyngealized consonants and vowels in Arabic. Other researchers, such as Anderson (1974), Halle (1989), Goad (1989), and Keyser & Stevens (1994) have argued that the feature for retracted tongue root should be distinct from one for advanced tongue root. To some extent, the debate is fueled by a lack of articulatory data on enough of the relevant languages. We have reviewed what is known articulatorily about the production of vowels in vowel harmony languages in §1.2.5.2, as well as other languages to which they are compared. However, comparisons using analyses of similar sets of data have not been performed. Our analysis of Akan and Arabic in subsequent chapters will investigate the articulatory similarity of the advancement and retraction of the tongue root found in the [ATR] language Akan, with a language which emphasizes retraction of the tongue root (and perhaps the rear dorsum) in the production of pharyngeals and pharyngealized segments. Akan has been previously investigated using factor analysis by Lindau (1987) and Jackson (1988a,b). We will reanalyze Akan here because the two previous analyses differed from each other and both lacked complete data sets, a problem which has been rectified in our analysis.

4.1 Language background

Akan is a Niger-Kordofanian language which belongs to the Tano group of the Volta-Comoë branch (Stewart, 1970; Trutenau, 1976) of the South Central Niger-Congo family (Bennett & Sterk, 1977).[1] It is spoken mainly in Ghana.

Akan has fourteen vowel phonemes, nine oral and five nasal, all of which can occur independently in monosyllabic noun and verb stems. These vowels are shown in (4-1) below.

(4-1) Akan vowel phonemes

	Set 1 [+ATR]		Set 2 [-ATR]			
oral	i	u	ɪ		ʊ	high
	e	o	ɛ		ɔ	mid
				ɑ		low
nasal	ĩ	ũ	ɪ̃		ʊ̃	high
				ɑ̃		low

Set 1 [+ATR] vowels on the left have an advanced tongue root and a lowered larynx position, resulting in an expanded pharynx, while Set 2 [-ATR] vowels on the right have a retracted tongue root and a raised larynx position, resulting in a contracted pharynx (Lindau, 1975, 1979; Tiede, 1990). Although pharynx width is usually dependent on

[1]The South Central Niger-Congo language family proposed by Bennett & Sterk (1977) generally encompasses the languages previously assigned by Greenberg (1963) to Kwa and Benue-Congo. Stewart (1989:219) uses the name 'New' Kwa to refer to Bennett & Sterk's Western South Central Niger-Congo. Williamson (1989:19) uses Niger-Congo for the language family name in place of Niger-Kordofanian and Atlantic-Congo for Bennett & Sterk's Niger-Congo.

tongue height in languages like English and German (Lindau, 1978:557-8), the same is not true of Akan. Lindau (1979:112) has shown that even after one subtracts out the amount of pharynx width that is correlated with tongue height, pharynx width is still highly correlated with [ATR] set affiliation.

X-ray films were taken by Mona Lindau in 1972 of four speakers of Akan (two male and two female), and she has kindly lent me her tracings from these films. Lindau (1975, 1979, 1987) provides discussion of her methodology and of the data. Three of her subjects spoke the Akyem dialect and one spoke the Asante (Ashanti) dialect. The two dialects are very similar and mutually intelligible. Measurements were taken from the tracings provided by Lindau, with the exception of the vowel /ɑ/ which was not included in Lindau's wordlist. By chance, its nasal counterpart /ɑ̃/ does occur in the carrier frame, and is the source of the tracings and measurements used here. Using copies of her original films, additional tracings were made using the set-up described in §3.2 and the two best were selected for measurement. The vowels used in this study are thus phonemically oral, with the exception of the nasalized low vowel /ɑ̃/.

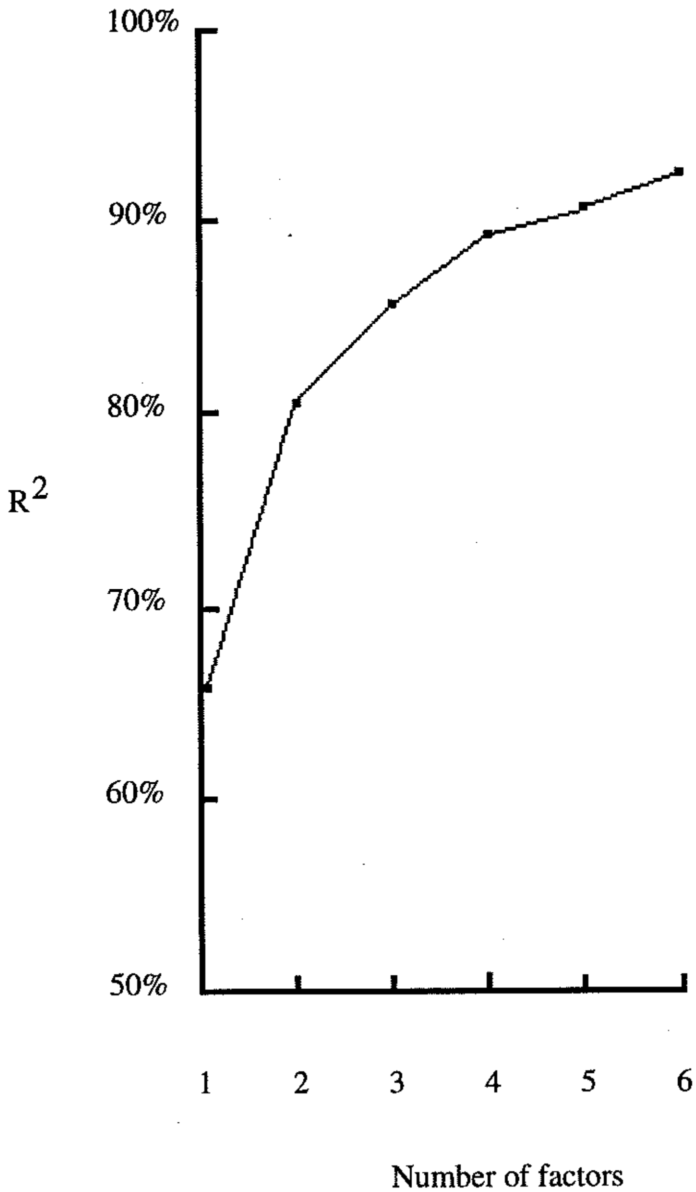
4.2 PARAFAC analysis of Akan

The Akan data set contained 1080 data points (30 measures x 9 vowels x 4 speakers). Of these, only twenty-six points had missing values. Most of these points occurred in segments where the vocal tract was shorter than the measurement grid, and thus did not intersect with the lowest gridline. Initial estimates were supplied to the program based on continuations of the lines marking the pharyngeal wall and tongue root. These points were treated as missing values in the analysis by entering a missing value subscript table, identifying their location in the data set. As was discussed earlier, the fit was not significantly improved by rescaling the measurement grid for cases such as these. It was also found that supplying initial estimates constrained the program from treating missing data points as wild cards (using them to absorb error to increase the fit).

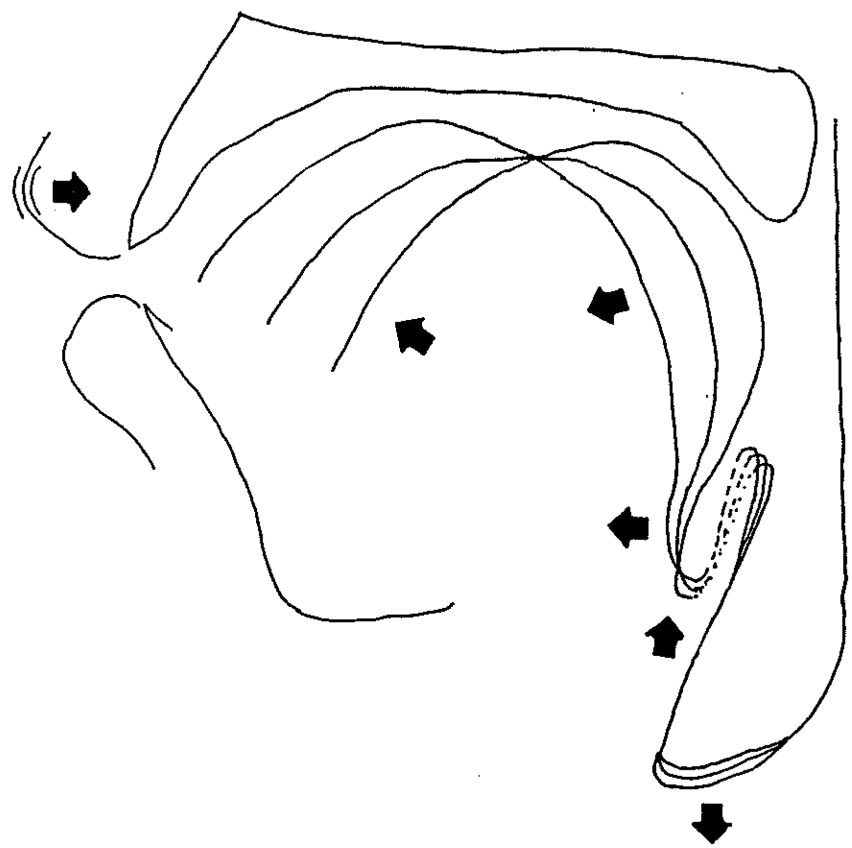
(4-2) summarizes how analyses at different dimensionalities (i.e., number of factors extracted) performed in terms of the criteria outlined earlier. Solutions at all dimensionalities converged, but those with four or more factors were not unique. There is a large improvement in fit (R^2) between the one- and two-factor solutions. R^2 values can be more readily appraised in (4-3). One way of determining the number of dimensions in the data is to locate sharp bends in the fit curve. Solutions at dimensionalities beyond the bend show a reduced rate of improvement in fit, and the additional factors are less likely to be significant. On this basis, the two-factor solution appears to be the optimum solution. However, as both the two-factor and the three-factor solutions meet the other criteria, we will consider these two solutions below.

(4-2) Evaluation criteria for PARAFAC analyses of the Akan data

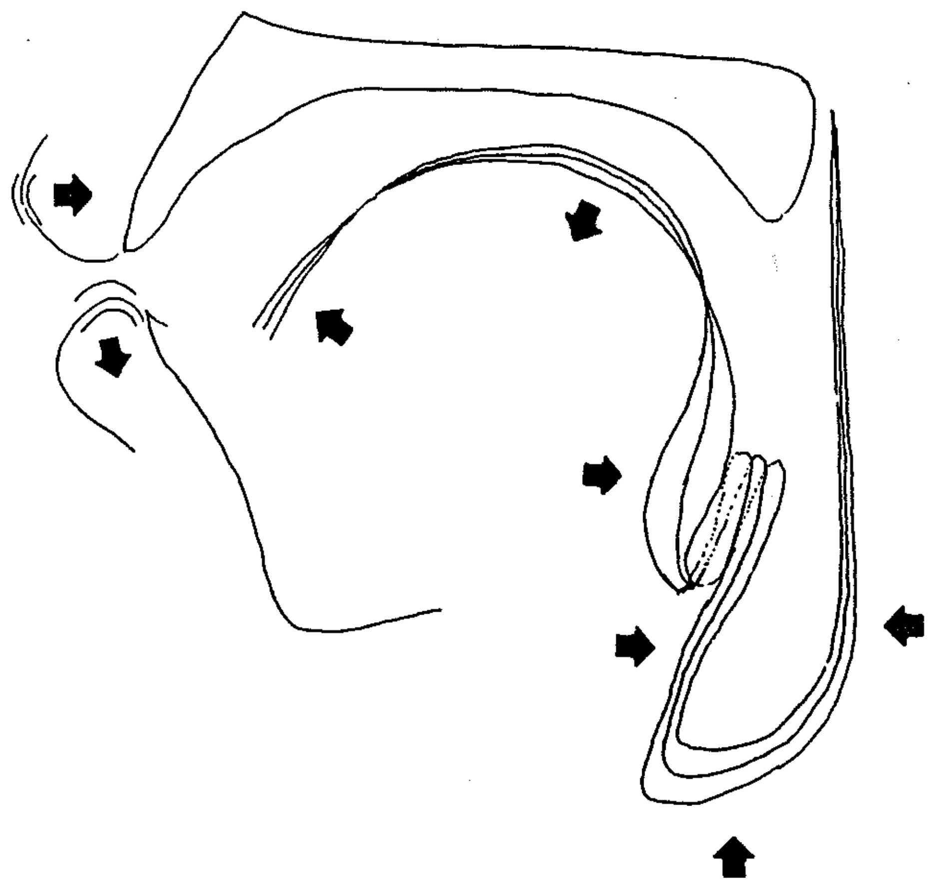
Number of factors	Converged (iterations in parentheses)	Unique	R2	System variation	Correlation between factors
1	yes (10,9,10)	yes	.66	yes	n.a.
2	yes (62,72,78)	yes	.81	yes	low
3	yes (337,314,157)	yes	.86	yes	mid
4	yes (332) no (600)	similar	.89	questionable	high
5	yes (598) no (600)	no	.91	questionable	high
6	yes (653,500,591)	no	.93	questionable	high



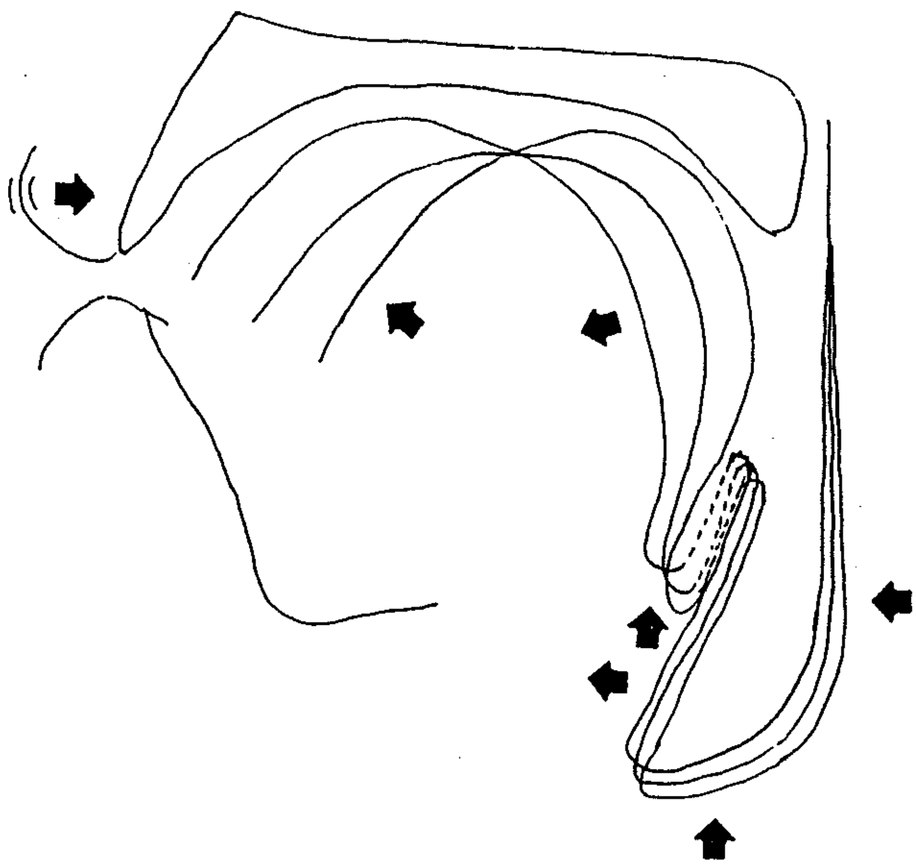
(4-3) Percentage of variance (R^2) accounted for by *n* factors in Akan.



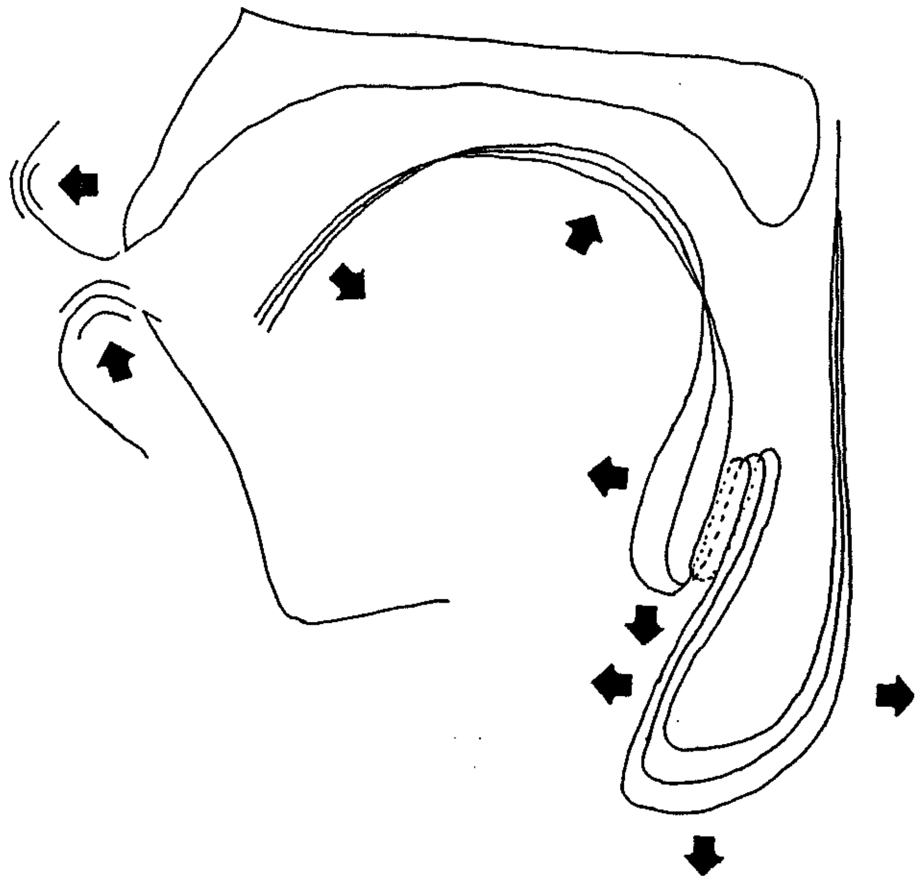
(4-4) Factor 1 of the Akan 2-factor solution.



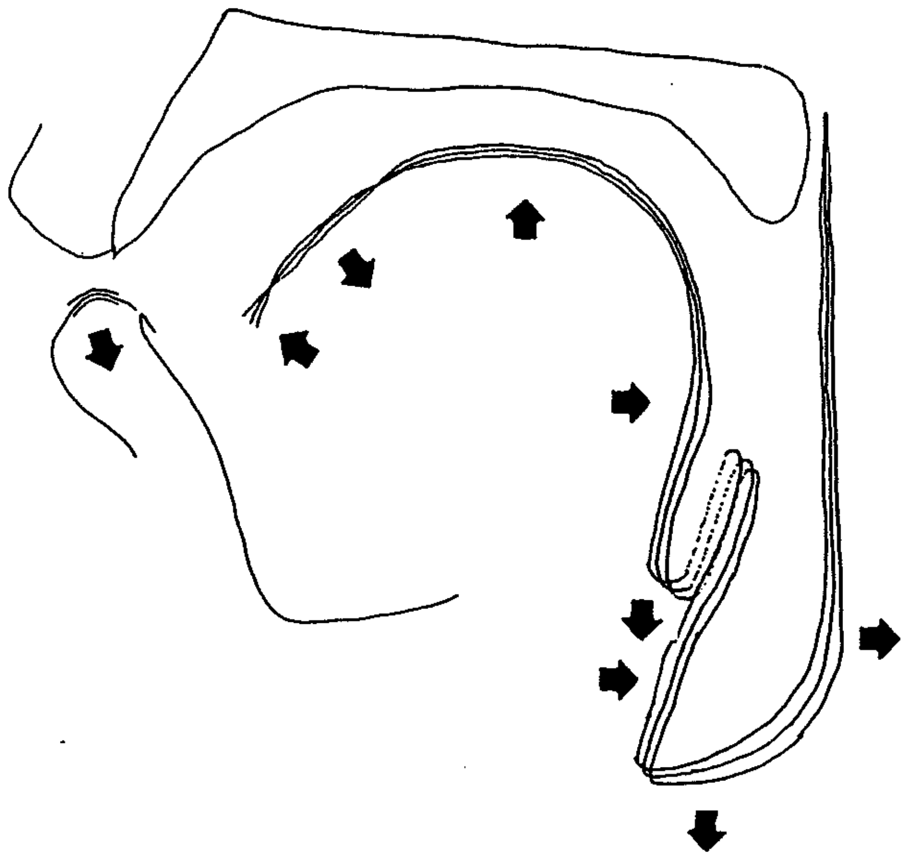
(4-5) Factor 2 of the Akan 2-factor solution.



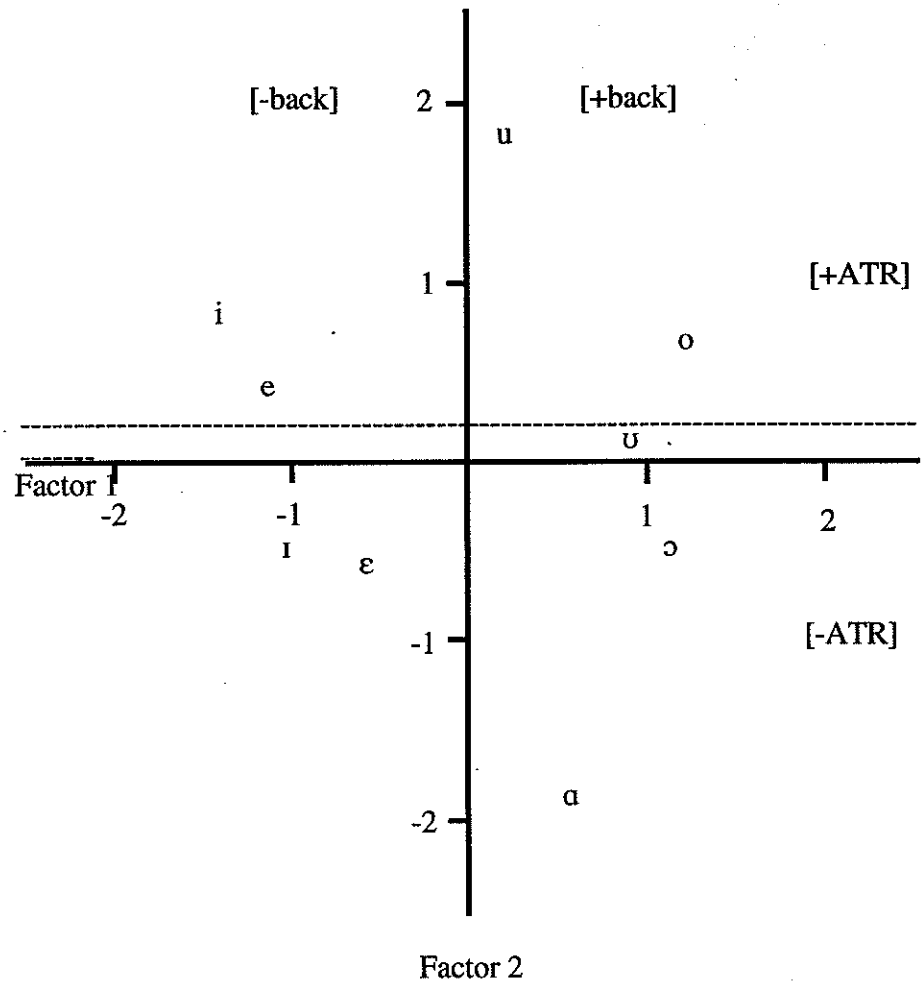
(4-6) Factor 1 of the Akan 3-factor solution.



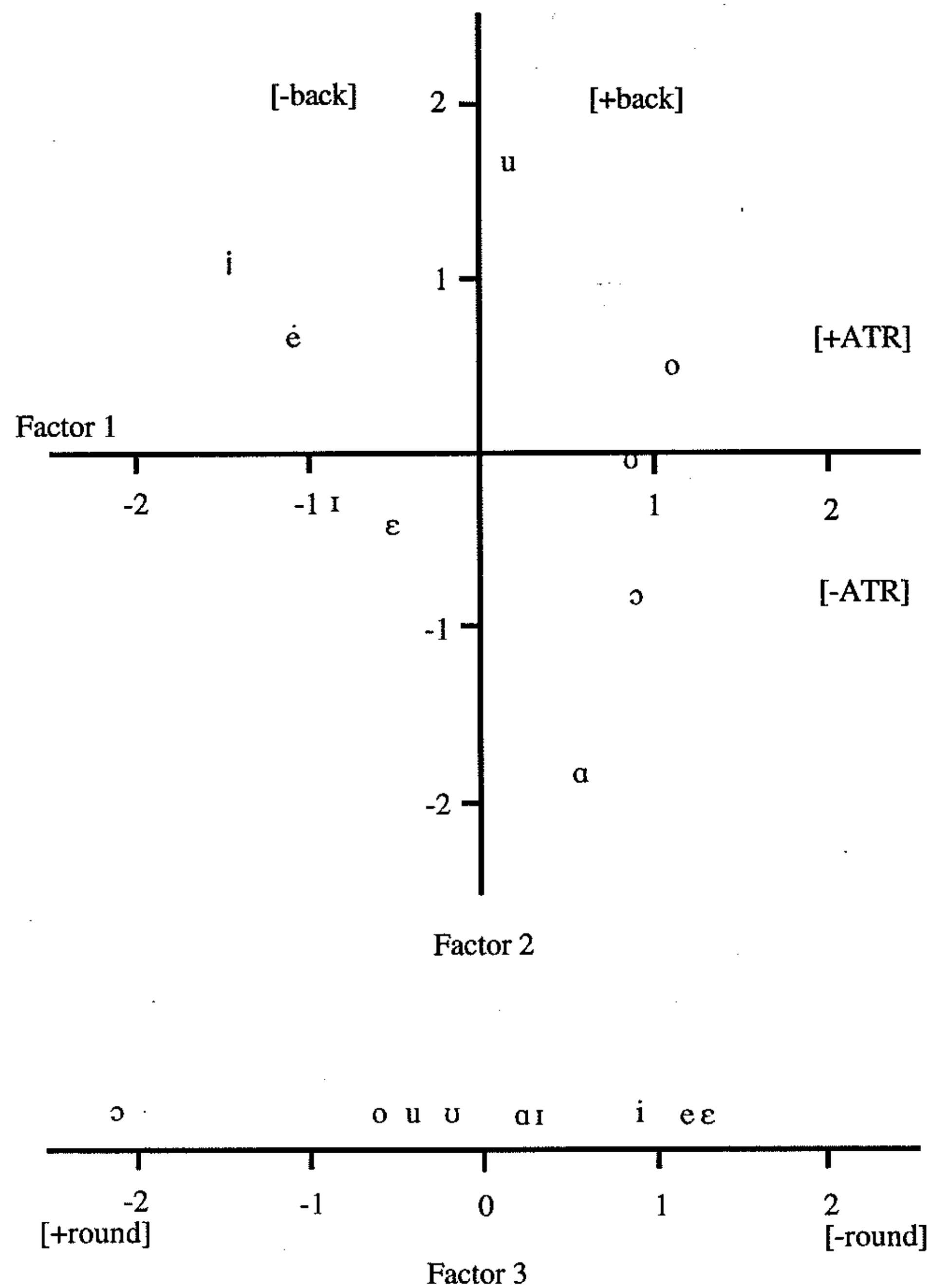
(4-7) Factor 2 of the Akan 3-factor solution.



(4-8) Factor 3 of the Akan 3-factor solution.



(4-9) Rotated vowel space (Mode B segment loadings) for the Akan two-factor solution.



(4-10) Rotated vowel space (Mode B segment loadings) for the Akan three-factor solution.

The articulatory displacements (from the mean position in the dataset) generated by the two- and three-factor solutions can be seen in (4-4)-(4-8). Each factor describes a type of underlying movement of the tongue and other structures and different segments are formed through combinations of varying amounts of these factors. In the text below we will discuss the articulatory displacements modeled by each factor using the words 'move' and 'movement'. However, it should be kept in mind that the factors are modeling underlying components for each dataset.

The first two factors in each solution are quite similar. The tongue movement in the first factors ((4-4)and (4-6)) is almost identical, although there are differences in the laryngopharyngeal area. In the two-factor solution, there is no movement in this area except some vertical larynx movement; as the tongue body moves up and forward the epiglottis rises but the larynx lowers. In the three-factor solution, the tongue root moves with the dorsum of the tongue, the epiglottis is pulled in the same direction as the larynx, and the pharyngeal wall is also pulled in the same direction as the tongue root. On physiological grounds, the movement of the latter factor is more plausible. There is also almost no difference in the second factor of these two solutions. The one difference is in the vertical movement of the epiglottis. In the three-factor solution, the epiglottis moves up and down with the larynx, while in the two-factor solution, it does not move at all. The former is a little more plausible physiologically. The third factor of the three-factor solution (4-8) describes a gesture in which the dorsum, tongue root, and pharyngeal wall all move together, and the epiglottis and larynx also move in tandem. The magnitude of these movements is not large, and it does not appear to be an especially significant factor.

(4-9) and (4-10) show the vowel space of these solutions. Factor 1 in both solutions divides [±back] vowels while factor 2 divides [±ATR] vowels. In the three-factor solution, the separation of the [±ATR] vowels is a little neater. In the two-factor solution, the [+high, +back, -ATR] vowel [ʊ] has a slight negative loading on Factor 2, while other [-ATR] vowels have positive loadings. Thus the three-factor solution gives slightly better resolution of the [ATR] feature, perhaps by factoring out movements not correlated with [ATR] into the third factor. Factor 3 divides [±round] vowels. (4-8) shows that as the dorsum moves back and up, there is some accompanying tongue root retraction independent of the tongue root retraction found in [-ATR] vowels. Thus the three-factor solution presents a somewhat "cleaned-up" version of the gestures producing [±ATR] vowels, and the factor loadings of this version will be used in the cross-linguistic analyses. However, in general terms, the Akan data set appears to only require two factors for descriptive adequacy. To test the appropriateness of using the first two factors from the three-factor solution, their loadings were input as the starting configuration for a two-factor analysis. By holding all modes fixed and not allowing additional iterations, we can determine the amount of variance accounted for by those two factors alone. The result was an R^2 of .77, which is four percent less than the original two-factor solution. If the program is allowed to increase the fit from this starting configuration through additional iterations, it re-converges to the original two-factor solution.

4.3 Discussion of the Akan three-factor solution

Any given vowel can be thought of as composed of some combination of the movements represented by these factors. The first factor (4-6) separates front vowels [i ɪ e ɛ] from back vowels [ɑ ɔ o ʊ u], and also contributes to distinguishing vowels of different heights. Front vowels are formed by movement (in the direction of the arrows) toward the palate and away from the uvula and upper pharynx together with forward movement of the pharyngeal wall and lower pharyngeal area. There is some larynx lowering. The opposite movement forms back vowels. The second factor relates principally to the tongue root and pharyngeal cavity and is discussed separately below. The third factor (4-8) provides adjustments for the differences between round and non-round vowels. Non-round vowels involve rearward movement (in the direction of the arrows) of the entire tongue root and the lower pharyngeal wall, which counters the effects of Factors 1 and 2 to some extent. Movements in the opposite direction affect round vowels.

The second factor (4-7) separates [±ATR] vowels. [-ATR] vowels exhibit retraction of the tongue root in the area just above the pocket of the epiglottis and general contraction of the lower pharynx.[2] This contraction is formed through forward movement of the pharyngeal wall, rearward movement of the tongue root below the epiglottis, and raising of the larynx. [+ATR] vowels display movement in the opposite direction, or expansion of the laryngopharynx. It was this expansion and contraction of the laryngopharynx that led Lindau (1979) to propose the feature [expanded] for [ATR], as [ATR] in Akan involves more than just retraction or advancement of the tongue root. However, other [ATR] languages like Ateso and Dho Luo do not share these changes in larynx position (Lindau 1975). Expansion/contraction of the pharynx may thus be specific to Akan.

The movements of the epiglottis and dorsal wall of the pharynx are noteworthy. The magnitude of movement of the epiglottis is less than that of the root of the tongue in Figure 4-7; the epiglottis thus appears to ride on the tongue root in Akan [±ATR] vowels, rather than independently retracting. Movement of the dorsal wall of the

[2]The actual positive and negative signs for this factor have been reversed so as to facilitate comparison with the two-factor analysis. Sign assignment is mostly a matter of chance.

pharynx takes place primarily in the laryngopharynx for [±ATR] vowels; there is very little movement in the upper oropharynx.

4.4 Discussion of previous PARAFAC analyses of Akan

Two previous analyses of the Akan data using PARAFAC were done by Lindau (1987) and Jackson (1988a). Lindau (1987) only extracted two factors, possibly because of lack of data on the low vowel. Her first factor resembles Factor 1 here (4-6), but the cross-over point (where the sign changes from positive or negative or vice versa) is further back in her analysis. The factor shown in (4-6) has more dorsum movement than hers, and can generate both i-like movements and u-like movements. Lindau's Factor 1 describes i-like movements and ɔ-like movements. Lindau's second factor separates [±ATR] vowels to some extent, but the vowel [ʊ] does not get classified as a [-ATR] vowel with just two factors, and this is so to a much larger extent than with the two-factor solution presented here.

Jackson (1988a) extracted three factors rather than two. His third factor separated the [±ATR] vowels, and is characterized mainly by vertical larynx movement. Jackson (1988a:89) suggested three reasons for the differences between his and Lindau's study. First, two of his factors are highly correlated; second, his study included measurements of two tokens of the vowel /ɑ̃/; and third, he made forty-four measures of each segment compared with Lindau's sixteen. Lindau's sixteen measures were only of the tongue body itself, and in particular did not include a measure of larynx position. Vertical height of the larynx is important to the production of the [ATR] feature in Akan, and accounts for most of the articulatory displacements generated by Jackson's third factor. A further reason for the differences between Lindau (1987) and Jackson (1988a), and also for the differences with this study, is that Jackson had 117 missing data points (98 due to the other two missing /ʊ̃/ vowels) which he allowed the program to estimate. I found that the PARAFAC estimates, especially for large numbers of missing data points, were not reliable - often positing impossibly high numbers for certain measures. Such a procedure allowed the program to use the missing data points as wild cards. In contrast, when estimates were supplied to the program, the resulting analysis was little different from one done with actual measurements for the two missing vowels. The procedure followed in this study thus allows for a more accurate extraction of factors and consequently more accurate information about articulations than in Jackson (1988a).

4.5 Summary

In this analysis of Akan, we have concluded that the three-factor solution yields the best linguistic solution. The first factor describes the movements used in producing front and back vowels, the second describes the movements for [+ATR] vs. [-ATR] vowels, and the third separates [±round] vowels. For [-ATR] vowels, pharyngeal constriction begins midway between the bottom of the uvula and the tip of the epiglottis, and continues to the larynx. Maximum constriction occurs at the pocket of the epiglottis. The constriction also involves raising of the larynx and advancement of the pharyngeal wall. We will turn next to Arabic, and see how these languages compare in their production of sounds in the pharynx.

CHAPTER 5 ARABIC

5.0 Introduction

Arabic dialects belong to the Semitic branch of Afro-Asiatic.. Arabic dialects contain four types of segments that are of interest to this study: pharyngeal, uvular and emphatic coronal consonants, and retracted vowels in emphatic domains. The emphatic consonants are sometimes referred to as velarized or pharyngealized, although we will continue to use the term emphatic, as velars, uvulars and pharyngeals do not have the same phonological effect as the emphatic consonants. Emphatic consonants are dental stops and fricatives with retraction in the pharynx; phonologically they cause other segments in a word to be retracted.[1] There is a limited amount of essentially random phonetic data on these sounds in a number of dialects. The Arabic dialects are spoken over a wide area from the Atlantic coast of Northern Africa to the Persian Gulf. A map of this area is shown in (5-1). The nine sources of x-ray tracings listed in (3-1), reflect this geographical distribution. Three studies are of North African Tunisian and Moroccan Arabic, three are of Iraqi Arabic, and there is one each of Damascan (Syrian), Qatari and Saudi Arabic. The first question that must be addressed, then, is the extent to which data from these dialects can be pooled together to form the basis of a composite study of Arabic.

5.1 Arabic dialects

Arabic dialect studies distinguish Western dialects (also known as Maghrebi Arabic) from Eastern dialects (Ambros 1977, Bateson 1967, Marçais 1960, Fleish 1960) and nomadic Bedouin dialects from sedentary dialects (Ambros 1977, Bateson 1967, Blanc

[1]This is an overly simplified description, which was discussed in greater detail in §1.2.3.

1964, Blanc 1962). The Western dialects are those spoken in Northern Africa from the Atlantic Coast to roughly a line stretching from Lake Chad to the Gulf of Sidra. Two criteria are often referred to in these divisions (Ambros 1977:1, Bateson 1967:101-4). Morphological differences in marking the singular and the plural are referred to when distinguishing Eastern dialects from Western dialects, while the voicing of the reflex of Classical Arabic[2] /q/ is used to distinguish nomadic and sedentary dialects; voiceless (/q k ʔ/) for sedentary dialects and voiced (/g/) for nomadic dialects. Bateson (1967:101) says the latter is the only feature that occurs in all nomadic-sedentary contrasts outside of Arabia. It is "[ʔ] in most cities of Syria and Egypt, [k] in some rural Palestinian dialects, [q] in Iraq and most cities of Northern Africa." (Ibid.). In Damascus, [q] is used in classicisms (Cowell 1964:4). In Eastern Arabian dialects (which includes Qatari), [q] is common in the speech of educated speakers although uneducated speakers use [g] except in the word [quraan, qurʔaan] 'Qur'an' [Koran] (Johnstone 1967:20). Thus, even in dialects where the colloquial sound system did not retain the Classical Arabic voiceless uvular stop, it survives in educated speech. All of the subjects of the x-ray films were educated speakers, and [q] is present in all films which included words in which it is historically appropriate.

Other generalizations can be made about these dichotomies. Western dialects tend to lose /ʔ/ (Bateson 1967:103). Western dialects have undergone more drastic changes affecting vowels and generally have lost all short vowels in open syllables (Bateson 1967:104, Marçais 1960:579). All dialects (Eastern and Western) have lost final short vowels; when epenthesis occurred to break up the resulting tautosyllabic consonant clusters, the preceding vowel was left in an open syllable and was then dropped in Western dialects (Bateson 1967:104). This has led to rather different looking (and

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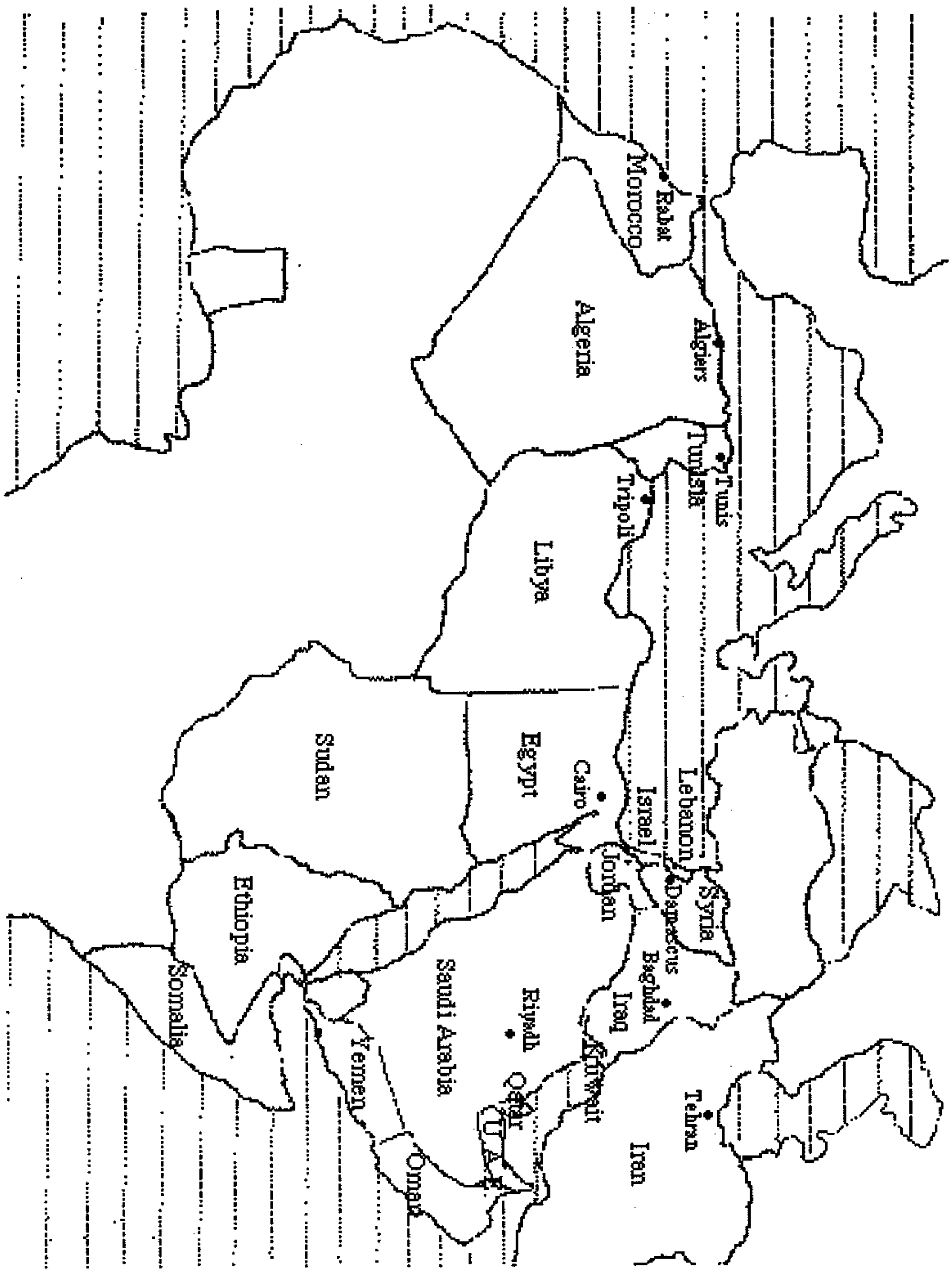
[2]The language of the Koran.

sounding) realizations of cognates in Eastern and Western dialects. An often-heard comment is that syllable structure, rhythm and stress differences impede comprehension even more than differences in individual segments. In addition, the North African dialects have "innovations in syntax like the evolution of a true definite article, varying expressions for possession, prefixes in the imperfect aspect of the verb, and borrowing and semantic shifts in vocabulary" (Irving 1962:58-9). Most sedentary dialects have lost interdental fricatives, turning them into dental stops, but the interdentals do survive in the major sedentary dialect of Tunisia (Bateson 1967:102). Sedentary dialects have lost gender distinctions in the plural of verbs and pronouns (Ibid.:102). However, as the nomadic invasions took place centuries ago, there are regional characteristics that cut across sedentary-nomadic lines (Ibid:97).

Educated speakers learn Classical Arabic and Modern Standard Arabic. Classical Arabic is the prestige form, and all books and newspapers, broadcasting and instruction are in Classical Arabic. In Modern Standard Arabic, certain simplifications of Classical Arabic are allowed, there have been some shifts in lexical meaning and borrowings from other languages, and there have been stylistic changes caused by contact with other languages. Ghazali (p.c.) says that educated speakers often slip into a somewhat more colloquial style which he calls "Middle Arabic". This is a form of Modern Standard Arabic without the case endings, which borrows function words from the vernacular and lexical items (usually nouns and verbs) from Classical Arabic. In the relatively formal setting of acting as a language consultant in front of cameras and tape recorders, most speakers in the x-ray studies probably used some version of Modern Standard Arabic. Metoui's speaker used some classicisms (the wordlist contained words with [-un] and [-u] endings which would not be pronounced in dialect), and Ali's speaker was judged to be using classicisms by another Iraqi speaker. The use of Modern Standard Arabic or



(5-1) Map of Arabic-speaking area

Classical Arabic by the subjects of these x-ray studies will tend to level some of the differences between the dialects. We will next compare the segment inventories and descriptions of these segments to see to what extent the individual segments might vary.

5.2 X-ray data

X-ray data on vowels is available only for Tunisian (Ghazeli 1977, Metoui 1989), Iraqi (Ali no date) and Syrian (Damascan) (Abramson and Ferguson 1962) dialects. Classical Arabic is often analyzed as having three short vowels /i a u/, three long vowels /iː aː uː / and two diphthongs /aj aw/ (Cantineau 1960:91, Bateson 1967:5). Maamouri (1967) analyzes Tunisian Arabic (of Tunis) as having essentially this system, while in Damascan Arabic, the diphthongs have generally become long mid vowels, although some contrasts with diphthongs still exist (Ferguson 1957). A full set of data can only be obtained for two environments: 1) plain contexts (i.e. not adjacent to a pharyngeal or uvular consonant, nor occurring in the same word as an emphatic consonant) and, 2) contexts adjacent to an emphatic consonant, in which distinctive vowel allophones occur. Although these dialects also tend to have allophonic variation next to pharyngeals and uvulars as well, these contexts do not appear consistently in the x-ray data, and thus will not be described here.

Ghazeli (1977:84) states that all vowels in Tunisian Arabic are backed when accompanying emphatic consonants. Maamouri (1967) describes the backed allophones of /i a u/ (short or long) respectively as [ɪ], a central, high to high mid unrounded vowel, [ɑ], a low back unrounded vowel, and [o] or [o̜], a mean mid or higher mid back rounded vowel. The plain versions are [i], [æ] or [ə], and [u] or [ʊ]. In Damascan Arabic, Ambros (1977:16) and Cowell (1964:9-12) only mention that /i/ and /a/ are retracted before emphatics; the back vowel /u/ is said by Ambros to have no noticeable allophonic variation. Both Ambros and Cowell describe the plain version of /a/ as [æ] and the backed version as [a] (similar to the vowel in American English 'pot'). Inspection of the Damascan x-ray tracings shows that all the vowels are backed (and sometimes lowered) in emphatic contexts. The mid vowels of Damascan will not be included in the analysis as they do not have equivalents in the Tunisian dialect. In Iraqi Arabic (Erwin 1963:17-25), both long and short vowels in nonemphatic environments are described as having the qualities represented by [i], [u], and [æ] or [a][3]. Erwin compares the vowels in emphatic contexts to American English vowels next to velarized or 'dark' laterals. For both long and short [iˤ], the vowel quality described is that of a high to mid central lax vowel. Short [uˤ] is a sound in between "bull and ball" (Ibid.:19), by which he perhaps means a lowered [ʉ] or a centralized [o], and long [uˤ] is described as being in between the peripheral vowels [u] and [o]. In emphatic contexts, the low vowel is described as ranging from a central vowel to a very back vowel.

X-ray data on Arabic consonants can be found for Tunisian (Ghazeli 1977, Ghazali no date), Moroccan (Boff Dhkissi 1983), Saudi (Bonnot 1977), Qatari (Bukshaisha 1985), and Iraqi (Al-Ani 1970, Ali no date, Giannini and Pettorino 1982) dialects. Language descriptions consulted include Al-Ani (1970) (Iraqi), Ambros (1977) (Damascan), Cowell (1964) (Damascan), Erwin (1963) (Iraqi), Harrell (1962) (Moroccan), Johnstone (1967) (Qatari), and Maamouri (1967) (Tunisian). The inventories of labial consonants vary, but are not useful for this study anyway. Interdentals occur in the Tunisian and non-urban Iraqi dialects, but not in the Moroccan, Damascan or Qatari dialects, and will be excluded from consideration here. Coronal /t tˤ

[3]Latif Ali (p.c.) says that the most common allophone of the low vowel in non-emphatic contexts in Iraqi Arabic is a low central vowel [a].

d $d^{ʕ}$ s $s^{ʕ}$ z ($z^{ʕ}$)/[4] are generally described as dental (Harrell 1962, Erwin 1963, Al-Ani 1970), although Ambros (1977:9) notes that the fricatives and emphatic stops are alveolar in Damascan Arabic. /k/ and /g/ range from medio-palatal to velar: palatal to velar in Damascan and velar in Moroccan, Tunisian, Qatari and Iraqi, although palatalization is noted to occur before high front vowels at least in Tunisian (Maamouri 1967:23) and Iraqi (Al-Ani 1970:32). The Damascan, Tunisian, and Moroccan inventories contain three uvular segments: /q χ ʁ/ (although Cowell 1964:4 lists them as post-velar). In Iraqi Arabic, Erwin lists the stop /q/ as post-velar and both fricatives as velar /xɣ/; Al-Ani lists /q ɣ/ as uvular, /x/ as velar, and /ɣ/ as velar next to /i/. /q/ appears to be the least variable of the series, and only /k/ and /q/ will be used in the analysis. All dialects have laryngeal /h ʔ/, but x-ray data is available only for Moroccan Arabic.

All dialects have pharyngeal /ħ ʕ /. Most of the phonological descriptions of these dialects do not give any articulatory description of these segments beyond a notation as fricatives, with the exception of Harrell (1962:6) for Moroccan: "These sounds are articulated by a simultaneous raising of the larynx and a movement of the root of the tongue toward the back wall of the throat." Ghazeli describes the pharyngeals in Tunisian as having a raised larynx and a contracted laryngopharynx as the result of "a backward movement of the root of the tongue and a forward displacement of the lower end of the back wall of the pharynx" (Ghazeli 1977:37). He also found raising of the blade and dorsum approximately 6 cm. behind the lips (ibid.). Delattre (1971:134) and El-Halees (1985:288) say that the constriction for /ħ/ is lower than /ʕ / in Lebanese Arabic and Iraqi Arabic, respectively. Other descriptions were discussed in §1.2.1.

[4]Most dialects only have three emphatic consonants: /$t^{ʕ}$/, /$s^{ʕ}$/ and /$d^{ʕ}$/ or /$ð^{ʕ}$/.

Description of the secondary articulation found in emphatic consonants is remarkably similar. Cowell (1964:6), Erwin (1963:12), and Ghazeli (1977:126) mention a retraction of the tongue in the upper pharynx and a depression of the dorsum under the palate. Ghazeli (1977) found the acoustic effects of emphasis to be very similar in the nine dialects and sub-dialects he investigated.[5] In all dialects, he found the most indicative acoustic cue to be the low onset or offset of the second formant of vowels adjacent to the emphatic consonants (Ghazeli 1977:77).

5.3 Examination of x-ray tracings

Tracings of x-rays which I made are given in Appendix A.II. A preliminary examination of these tracings shows the extent to which they agree or differ with previous articulatory descriptions. We will first look at tracings from the film made by and of Ghazali[6] in Appendix A.IIa.2-15. /s/ and /$s^{ʕ}$/ (IIa.2-3) show a slight difference in the area below the uvula and above the epiglottis. The dorsum of the tongue is slightly retracted in /$s^{ʕ}$/, while the tongue root shows no movement from its position for /s/. There is little difference between the two in the shape of the dorsum under the anterior half of the hard palate. In the pair /t/ /$t^{ʕ}$/ (IIa.4-5), the anterior dorsum of /$t^{ʕ}$/ is slightly lower than /t/, but not particularly concave, or depressed, as previous descriptions might have led us to expect. In /$t^{ʕ}$/, both the tongue dorsum and the tongue root are quite retracted in comparison with /t/, and the center of the retraction appears to be at the level of the epiglottis rather than higher, as with /$s^{ʕ}$/. /k/ (IIa.6) is palatal rather than velar as previously described. /q/ is uvular, and quite noticeably affects the size of the pharynx

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[5]Three Tunisian varieties: Tunis, Sahel (Sousse), and Ghoumrassen, two Libyan varieties: Zaouria and Tripoli; plus Algiers Algerian, Cairo Egyptian, Northern Bedouin Jordanian, Adamiyya Baghdad Iraqi (Ghazeli 1977:26).

[6]Salem Ghazeli later used the spelling Ghazali. We use the spelling 'Ghazali' here to indicate the x-ray film made by (and of) him.

from the uvula to the larynx: the pharynx is much narrower throughout, and the epiglottis is only a millimeter from the dorsal wall. The larynx is raised to a height comparable with /ħ/ in IIa.8. In /ħ/ and /ʕ/, we find retraction of the tongue root only and a contraction of the laryngopharynx. The rear dorsum is not retracted. The dorsum of the tongue is in a shape quite similar to [æ] in IIa.12: the anterior dorsum is both fronted and raised. The tongue body of [ɑ] (IIa.13) on the other hand is much lower, and does not show the pyramidal shape of /ħ/, /ʕ/ and [æ]. In [ɑ], the tongue root at the epiglottis is slightly more retracted than [æ], but the laryngopharynx is not contracted. The main difference between [æ] and [ɑ] appears to be in the height and frontness of the tongue dorsum. The vowels [i] and [iˤ] (IIa.10-11) look quite different from each other. [i] has a very narrow constriction between the blade and anterior dorsum of the tongue and the anterior third of the hard palate. The center of the rear dorsum is much lower than the sides (both lines are indicated in the tracing). In [iˤ], the anterior constriction is not as narrow, and the constriction is lengthened to include most of the hard palate. The rear dorsum is much backer than [i], and the epiglottis is slightly retracted. The larynx is a few millimeters higher in [iˤ] than [i]. The dorsum in [u] (IIa.14) is highest in the mid-palate area, with a narrowing extending past the uvula. The anterior dorsum of [uˤ] (IIa.15) is much lower under the palate, and the rear dorsum is much closer to the uvula. There is little difference in the height of the larynx.

Turning to the tracings of Ali's Speaker 2 in Appendix A, IIb.2-15, we can compare the vocal tract shapes of an Iraqi speaker with those of Ghazali described above. /s/ and /sˤ/ (IIb.2-3) differ more in the anterior dorsum than Ghazali's did: /sˤ/ is lower and slightly concave. Both the tongue root and the rear dorsum are retracted in /sˤ/, so that the narrowest constriction is in the mid pharynx, just above the tip of the epiglottis. There is more tongue root retraction than was seen in Ghazali's /sˤ/. With /t/ and /tˤ/

(IIb.4-5), there is little difference in the anterior dorsum, and the retraction in /tˤ/ is very similar to that in /sˤ/. /k/ (IIb.6) is palatal here as well, and the uvular stop /q/ (IIb.7) is very similar to Ghazali's. In /q/, the pharynx is especially narrow from the uvula to the tip of the epiglottis, and although the tongue root and epiglottis do not appear to be particularly involved, the larynx is raised and the lowest portion of the laryngopharynx is constricted. There were no words in Ali's film which contained /ħ/ and /ʕ/. Vocal tract shapes for these two consonants were initially estimated by comparison with the tract shapes for another Iraqi speaker (Al-Ani 1970:74) (IIb.8-9).[7] Al-Ani's speaker also showed a raised front dorsum for /ħ/ and /ʕ/, and it is even fronter than Ghazali's. Constriction in the pharynx is caused by the rear dorsum as well as the tongue root. The vowel [i] (IIb.10) has its narrowest constriction where the root of the front incisor meets the flatter portion of the hard palate. The anterior dorsum of [iˤ] (IIb.11) is much lower than [i], and both the rear dorsum and the tongue root are retracted. The center of constriction in [iˤ] is midway between the tip of the uvula and the tip of the epiglottis. [a] (IIb.12) has a much flatter dorsum than Ghazali's [æ] (IIa.12). The Iraqi [a] has a much more rounded, neutral tongue shape, which seems to fit its description as a central low vowel by Ali rather than a front low vowel. [ɑ] (IIb.13) has a very low anterior dorsum and a retracted rear dorsum and tongue root. The narrowest constriction is like that in [iˤ], midway between the tip of the uvula and the tip of the epiglottis. The constriction in [uˤ] (IIb.15) is much higher, and is centered around the tip of the uvula. This [uˤ] is not quite as back as Ghazali's [uˤ], and the anterior dorsum is somewhat higher as well. [u] was on Ali's wordlist but was skipped by this speaker, and an estimated vocal tract shape was made from [uˤ].

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[7] See §3.5. These 'measurements' were notated as initial estimates for missing data and PARAFAC subsequently improves on the estimate.

In summary, the pharyngeal constriction in emphatic segments varies within the speech of a single speaker so that it sometimes appears to be formed only by retraction of the rear dorsum alone, and at other times to be formed by both the rear dorsum and the tongue root. In the first case, the narrowest constriction is closer to the tip of the uvula, and in the latter, closer to the tip of the epiglottis. The area below the epiglottis tends not to be involved, with one exception (Ghazali's /tˤ/ in IIa.4). Larynx height does not seem to vary in a consistent way. The vowel allophones [iˤ] and [uˤ] are backed in comparison to their non-emphatic counterparts, and [ɑ] is lowered in comparison with [æ] or [a]. In [iˤ], it appears that both the tongue root and the dorsum are involved in the retraction, while in [uˤ], it appears that just the dorsum is involved.

The uvular /q/ shows some similarities to the pharyngeals /ħ/ and /ʕ/ in that it causes narrowing throughout the pharynx (including the area around the tip of the epiglottis which is important in the articulation of pharyngeals), raising of the larynx and contraction of the laryngopharynx. The pharyngeals /ħ/ and /ʕ/ appear to be formed by movement of the tongue root only. The epiglottis lies fairly flat against the tongue root and does not seem to be operating independently. This is true also of the very clear x-rays of Qatari Arabic in Bukshaisha (1985).

Production of the segments discussed above appears to be sufficiently similar to attempt an analysis by PARAFAC. As the majority of the x-ray sources focus on either consonants or vowels rather than both, consonants and vowels will be analyzed separately. §5.4 will discuss analysis of Arabic vowels and §5.5 will discuss analysis of Arabic consonants.

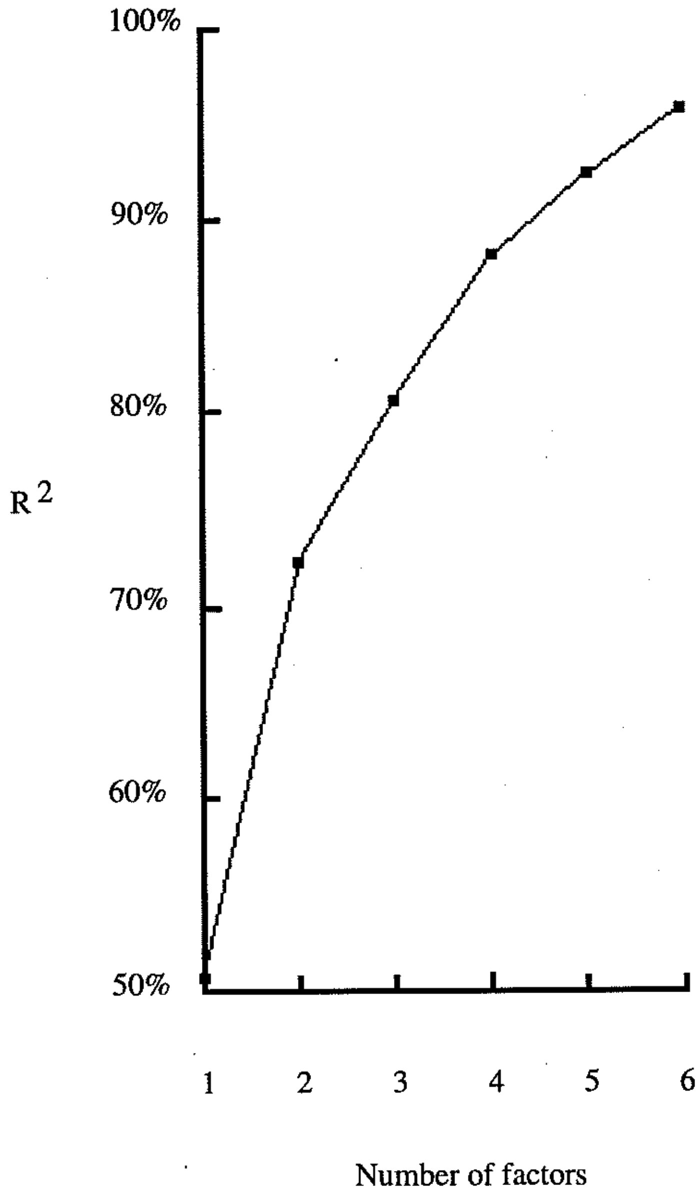
5.4 PARAFAC analysis of Arabic vowels

5.4.1 Data selection

Data on vowels was available for five speakers: two of Tunisian Arabic (Ghazali (no date), Metoui 1989), one of Iraqi Arabic (Ali (no date)), and two of Syrian Arabic (Abramson and Ferguson 1962). Only six vowels which have similar descriptions across the dialects were analyzed: [i, iˤ, æ or a, ɑ, u, uˤ]. The two Syrian speakers had more missing data as the laryngopharynx was not visible within the film frame, and at times the lips were out of the frame as well. The first Syrian speaker was missing 77 points out of 180 data points (43%) and the second speaker was missing 61 out of 180 (34%). With all five speakers, there are 184 data points missing out of 900 (20%). If the two Syrian speakers are excluded, the amount of missing data drops to 46 out of 540 (9%).

Data from only three speakers, excluding the two Syrian speakers, was ultimately used. Analysis of data from all five speakers yielded an interpretable analysis at two factors with a reasonably high R^2 of .79, but the factors were very highly correlated (.7-.8). Analysis of data from four speakers, excluding the second Syrian speaker, yielded factors which were highly inversely correlated. The solution for five speakers was similar to the solution for three speakers, but one crucial difference in the first factor yielded lower between-factor correlations in the solution for three speakers.

For the three-speaker data set, the optimum number of factors is two. The R^2 values for different numbers of dimensionalities are plotted in (5-2). The sharpest break in the curve occurs when two factors are extracted. The three factor solution did converge and was close to being unique, however, the factors were all very highly correlated (.97-.99). (5-3) summarizes the results of PARAFAC analyses in terms of the criteria outlined in §3.4. The Mode C loadings for the two-factor solution are given in (5-4).



(5-2) Percentage of variance (R^2) accounted for by *n* factors for Arabic vowels.

(5-3) Summary of PARAFAC analyses for the Arabic vowel solution for three speakers

Number of factors	Converged (iterations in parentheses)	Unique	R^2	System variation	Correlation between factors
1	yes (10, 14, 10)	2/3	.51	yes	n.a.
2	yes (46, 42, 40)	yes	.73	yes	low
3	no (600) yes (552, 536)	yes	.81	?	high
4	no (600, 600) yes (535)	n.a.	.88	?	high
5	no (600, 600, 600)	n.a.	n.a.	n.a.	n.a.

(5-4) Mode C (speaker) loadings for the Arabic vowel solution for three speakers (third run/trial)

	Factor 1	Factor 2
Metoui	1.454	1.779
Ghazali	3.732	2.155
Ali	2.074	3.262

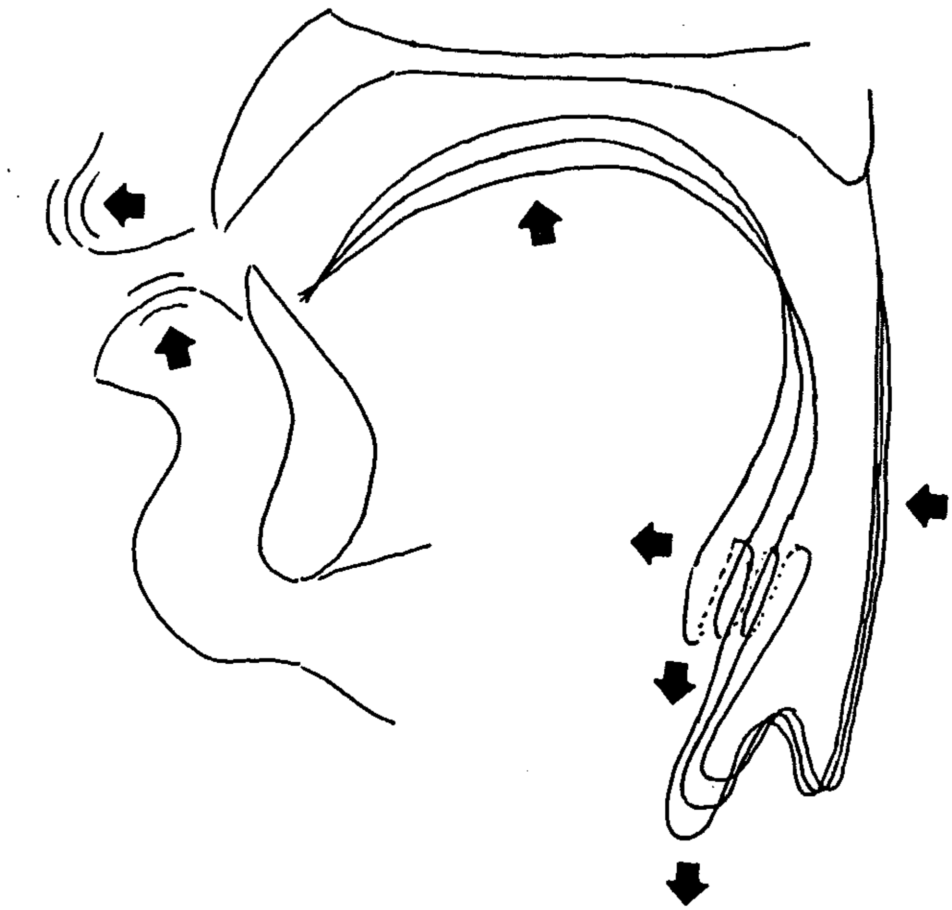
5.4.2 Discussion of the two-factor Arabic vowel solution for three speakers

Figures (5-5) and (5-6) illustrate the articulatory displacements generated by Factors 1 and 2. Factor 1 balances displacements of the blade and anterior dorsum with movements of the rear dorsum in the upper pharynx. As the blade rises towards the maxilla, the rear dorsum of the tongue is fronted, and as the rear dorsum is retracted, the front of the tongue assumes a very low position. The magnitudes of the movements of these two parts of the tongue are roughly equal. The cross-over point, where the weightings change signs, is approximately at the beginning of the soft palate. The main difference with the solution for five speakers was that the cross-over point was much farther back so that the displacements centered on the mid-palate and the mid-pharynx. The backer cross-over point made the first and second factors too similar, which led to the high correlations. From (5-4) we see that Ghazali loads higher on Factor 1 than on Factor 2.

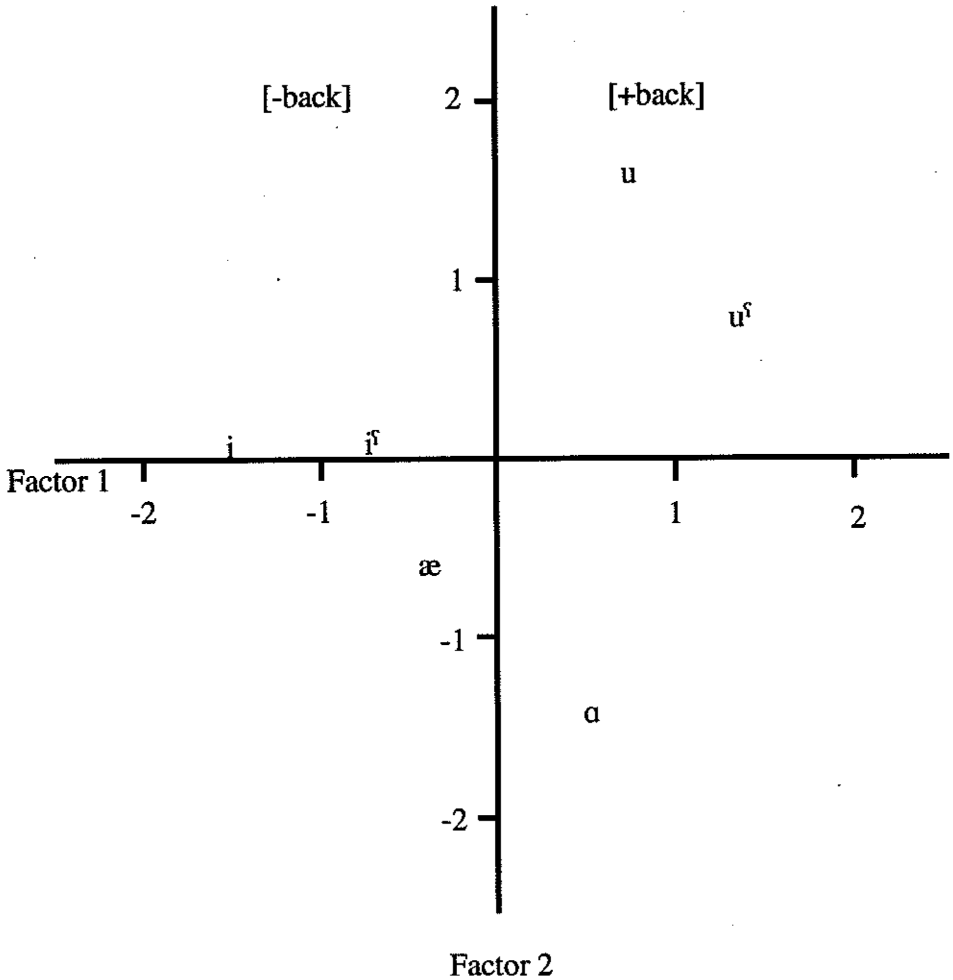
In the second factor of the solution for three speakers (5-6), the cross-over point has shifted backwards to below the tip of the uvula. This factor balances movements of the dorsum under the palate with movements of the tongue root centered at the tip of the epiglottis. The magnitude of tongue root movement is slightly larger than that of the dorsum, and retraction of the tongue root is coupled with vertical raising of the larynx. The pharyngeal wall is contracted slightly as well. As can be seen from (5-4), Metoui and Ali have a higher loading on this factor than on Factor 1.

Figure (5-7) shows the vowel space for the three-speaker solution. The signs of the weightings of Factor 1 have been reversed in order to plot the vowels in the same orientation as an IPA vowel chart. The first factor separates the front vowels [i, iˤ, æ] from the back vowels [ɑ, u, uˤ]. The high front vowels [i, iˤ] are completely determined by this factor. The second factor distinguishes [u, uˤ], which are formed by a very palatal movement, from the low vowels [æ, ɑ], which are formed by retraction of the tongue root and raising of the larynx. Thus, neither factor compartmentalizes the vowels in emphatic contexts from those in non-emphatic contexts, in contrast to Akan where we were able to isolate a single factor which discriminated [±ATR] vowels. Here, one cannot draw a line on the vowel space figure which would neatly separate the two categories. However, pairs of emphatic/non-emphatic vowels show relative differences along the Factor 1 axis: [iˤ, uˤ, ɑ] all have less anterior dorsum raising and more retraction of the rear dorsum in the upper pharynx than do [i, u, æ]. The [i, iˤ]

(5-5) Arabic vowel Factor 1 (from analysis of three speakers: Metoui, Ghazali, Ali)



(5-6) Arabic vowel Factor 2 (from analysis of three speakers: Metoui, Ghazali, Ali)



(5-7) Vowel space from the analysis of three speakers of Arabic (Metoui, Ghazali, Ali). Factor 1 axis reversed to show same orientation as IPA vowel chart.

distinction is made entirely through differences in their weightings on Factor 1. [$u^{ʕ}$] and [ɑ] are distinguished from [u] and [æ] respectively by a combination of rear dorsum retraction in Factor 1 and tongue root retraction in Factor 2. The articulatory correlate of emphasis for these three speakers takes the form of a shift in the primary articulatory domain towards a backer, more constricted articulation, which is vowel dependent. There may be a greater unity in their acoustic correlates, e.g., a lowering of F_2, in which case emphasis would have more of an acoustic target than an articulatory one.

5.4.3 Comparison between Akan and Arabic vowels

The factor in Arabic which separates the emphatic vowels is most similar to the Akan factor which separates front and back vowels. There is a slight difference in the constriction location in the two analyses: in the upper pharynx below the uvula for Arabic and at the uvula for Akan.

Akan Factor 2, which separates [±ATR] vowels, is characterized by a very low constriction between tip and pocket of the epiglottis. Arabic has a similar constriction, but it is used for low vowels. Noteworthy is the fact that Akan Factor 2 uses no blade movement, only movement of the tongue root, larynx and pharynx wall, whereas in Arabic tongue root movement is balanced by movement of the blade.

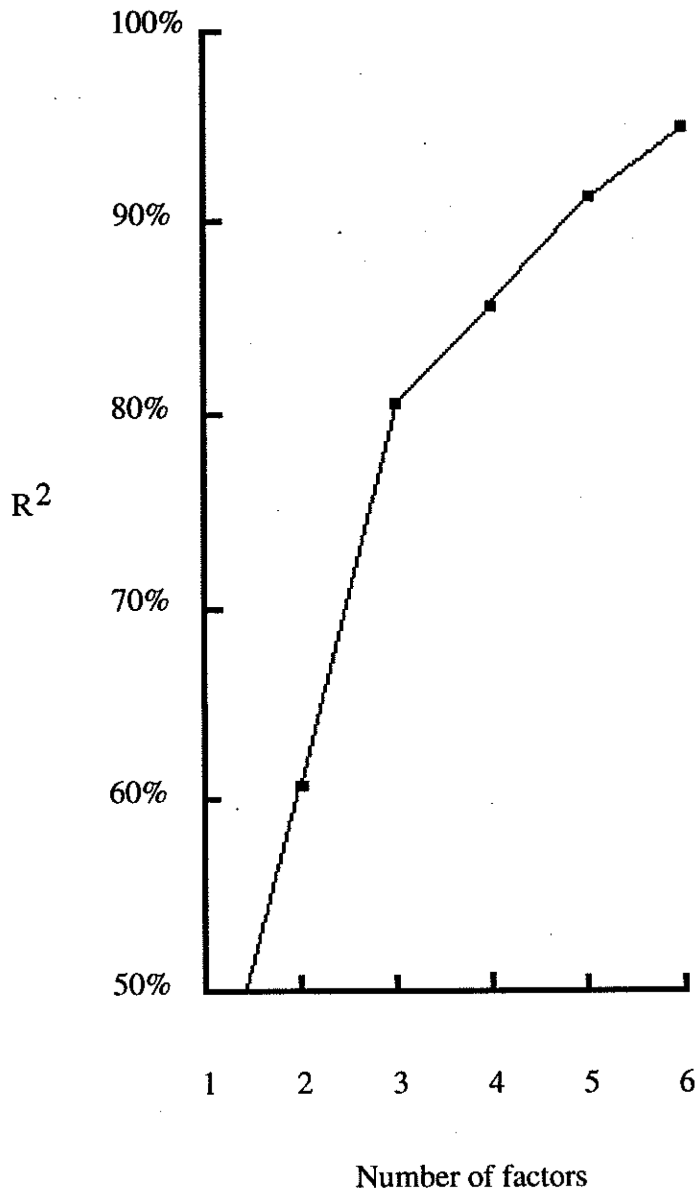
One of our questions has been answered. Emphatic vowels do not have a constriction at the same place as [-ATR] vowels. However [-ATR] vowels and the low vowel [ɑ] would seem to share the same place of articulation.

5.5 PARAFAC analysis of Arabic consonants

5.5.1 Data selection

Potentially, there are eight sources of data on Arabic consonants for a total of nine speakers: one of Tunisian Arabic (Ghazali (no date)), one of two speakers of Syrian Arabic (Ferguson & Abramson 1962), three of Iraqi Arabic (Al-Ani 1970, Giannini & Pettorino 1982, Ali (no date)), one of Moroccan Arabic (Boff Dhkissi 1983), one of Qatari Arabic (Bukshaisha 1985), and one of Saudi Arabic (Bonnot 1977). I wanted to include eight segments in the PARAFAC analysis: [s, sˤ, t, tˤ, k, q, ħ, ʕ], in order to balance four coronals against four non-coronals, and two emphatics against two pharyngeals. [q] was included to see if it patterned with either the emphatics or the pharyngeals, and [k] was included to provide an additional dorsal articulation to balance [q]. There were two difficulties in using x-ray tracings from the above sources: one was the spottiness of segments included in published tracings, and the other was the exclusion of the laryngopharyngeal area in certain sources. I was able to get the largest number of segments when I had access to the original films and could make the tracings myself. These consisted of films made by Ghazali, Ali, and Ferguson & Abramson. Three sources had to be eliminated: Boff Dhkissi and Bonnot because they contained too few segments, and Giannini & Pettorino because their published tracings were of different sizes. The area below the epiglottis was often not included in published tracings, and was also not visible in the Ferguson & Abramson film, as that area was outside of the film frame. Ghazali and Ali had no or little missing data. Ferguson & Abramson, Al-Ani, and Bukshaisha had similar amounts of missing data, the first two due to lack of data on the laryngopharynx, and Bukshaisha due to missing segments. PARAFAC analysis was limited to a maximum of five speakers because of the amount of missing data. Trial analyses were performed on three different five-speaker combinations, four different four-speaker combinations, and one combination of the three speakers with the most complete data sets. As will be shown below, the optimum number of factors for describing this data set appears to be three. At this dimensionality, the different four-speaker combinations did not work out at all: either the solutions did not converge, or the solutions were not unique, and two five-speaker solutions were eliminated due to high correlations between the factors. One five speaker combination and the one three speaker combination yielded results which meet the criteria discussed in §3.4: convergence, uniqueness, adherence to the system variation assumption, relative amount of increase in the values of R^2 between solutions, parsimony, low correlation between factors, and interpretability of factors. The three-speaker combination, consisting of data from Ghazali, Ali, and Bukshaisha, had very low factor correlations, while the five-speaker combination, using data from Ghazali, Ali, Abramson and Ferguson, and Al-Ani, had a moderate correlation between the first two factors.

The solution which best met the criteria for a sound factor analysis solution was a combination of three speakers, one each of Tunisian, Iraqi and Qatari Arabic, with an R^2 of .81. Figure (5-8) shows the R^2 values for different numbers of dimensionalities. The sharpest break in the curve occurs when three factors are extracted. The between-factor correlations are very low for this solution, with the highest in Mode A (vocal tract profile) being 0.249. In (5-9), the results of PARAFAC analyses are summarized in terms of the criteria outlined in §3.4. The Mode C loadings for the two-factor solution are given in (5-10).



(5-8) Percentage of variance (R^2) accounted for by *n* factors for Arabic consonants, solution for three speakers (Ghazali, Ali, Bukshaisha). R^2 for one-factor solution = 36%.

(5-9) Summary of PARAFAC analyses for the Arabic consonant solution for three speakers

Number of factors	Converged (iterations in parentheses)	Unique	R^2	System variation	Correlation between factors
1	yes				n.a.
2	yes (133, 71, 53)	close	.61	yes	low
3	yes (227, 127, 158)	yes	.81	yes	low
4	no (600) yes (589,300)	no	.86	yes	high
5	yes (546, 389, 378)	2/3	.92	yes	high

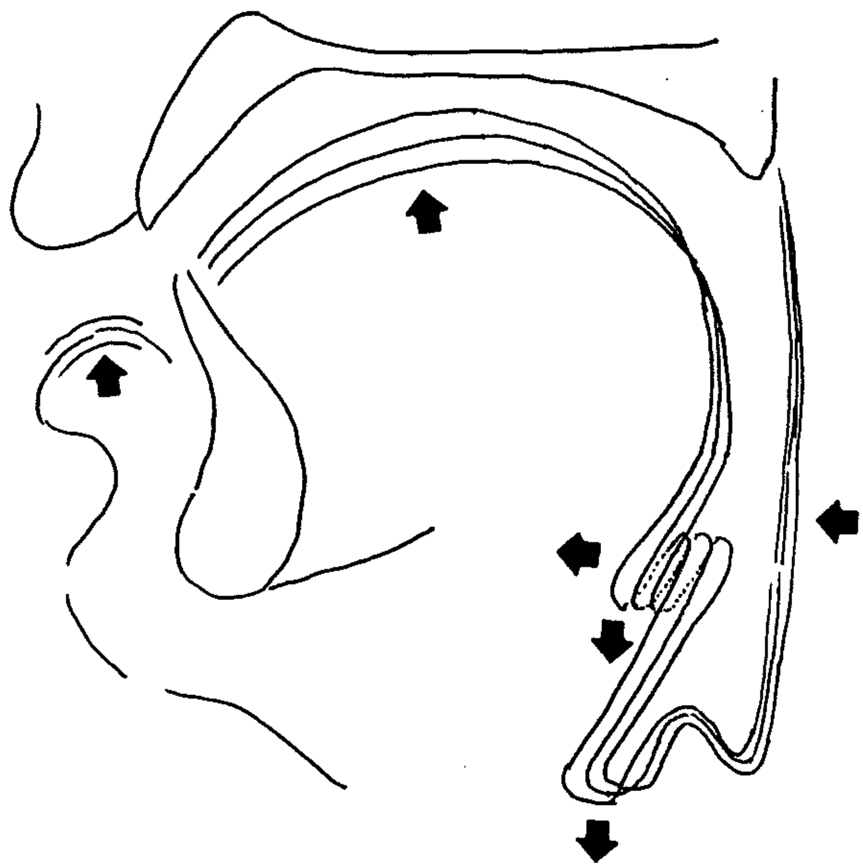
(5-10) Mode C (speaker) loadings for the Arabic consonant solution for three speakers (second trial/run)

	Factor 1	Factor 2	Factor 3
Ghazali	1.764	2.575	2.345
Ali	2.074	1.126	1.632
Bukshaisha	2.804	2.119	0.4771

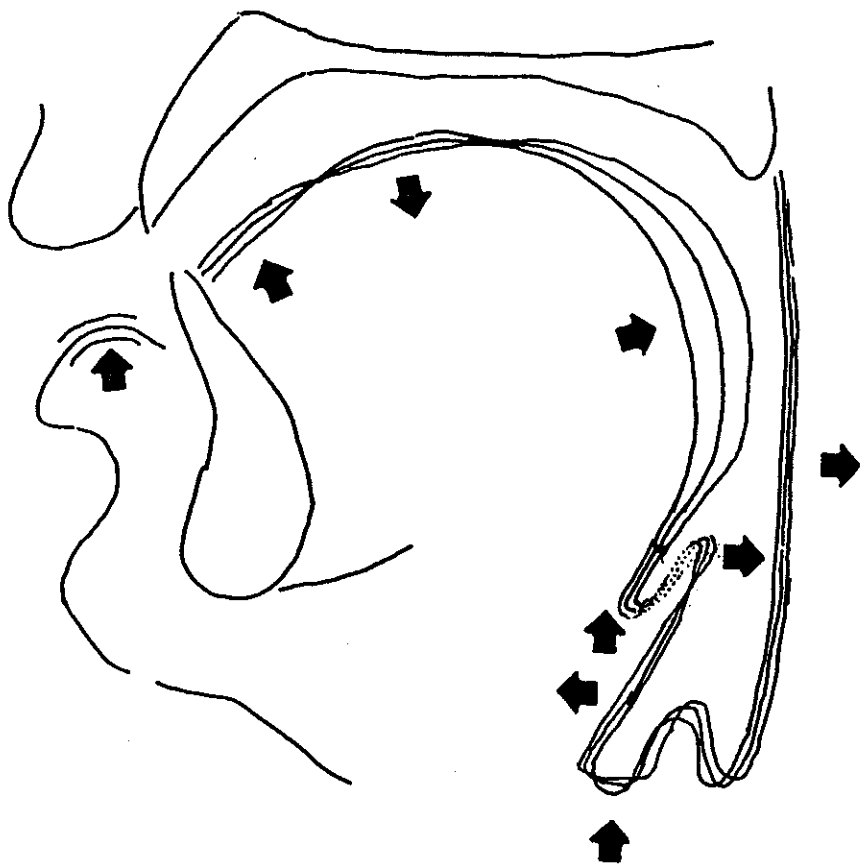
5.5.2 Discussion of the three-factor solution for three speakers

The first factor (5-11) separates the coronal segments [s, sˤ, t, tˤ] from the non-coronals [k, q, ʕ, ħ]. Primary movement is in the tip and tongue blade, with flattening of the blade under the maxilla as the tip rises. Retraction (backing) of the rear dorsum above the tip of the epiglottis and lowering of the larynx accompanies tip raising. Some of this movement in the pharynx is subtracted out for non-emphatic [s, t] by factors 2 and 3.

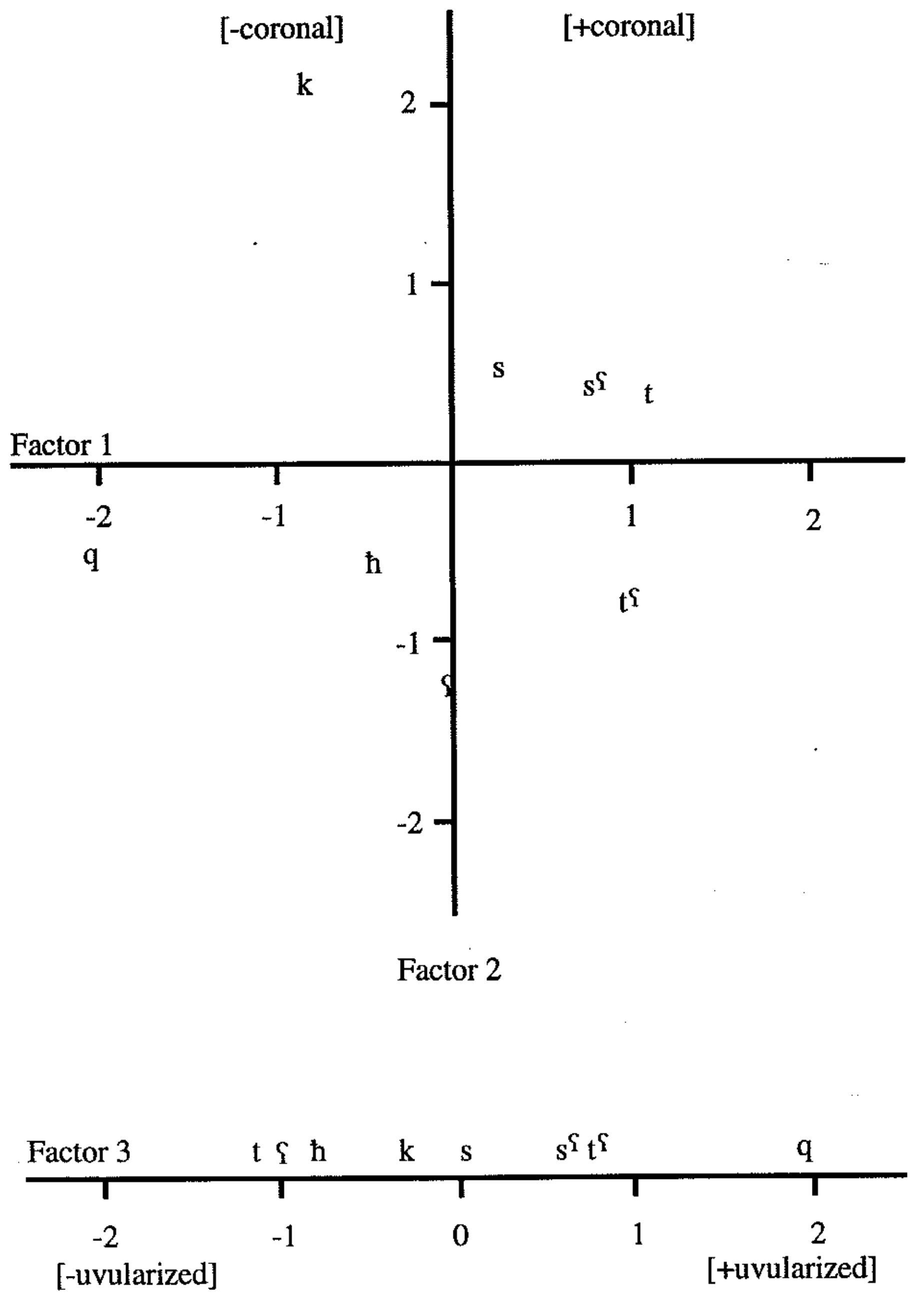
(5-11) Arabic consonant Factor 1 (solution for three speakers).



(5-12) Arabic consonant Factor 2 (solution for three speakers)



(5-13) Arabic consonant Factor 3 (solution for three speakers)



(5-14) Arabic consonant space from the solution for three speakers.

Factor 2 (5-12) separates low, back segments from non-low, non-back segments, [ʕ] at the low,back end of the spectrum and [k] at the other. [$t^{ʕ}$, q, ħ] are also grouped with [ʕ]. For [ʕ], (movements in the opposite direction of the arrows), the tongue root moves back primarily at the pocket of the epiglottis, but retraction occurs from below the uvula to the larynx and is accompanied by raising of the larynx and retraction of the pharyngeal wall (widening the cavity). Retraction of the tongue root is balanced by lowering of the tongue blade. As the tongue root moves forward, the larynx is lowered but the pharyngeal wall is advanced (constricted). This consonant factor is very similar to Arabic vowel Factor 2.

The third factor (5-13) mainly provides a constriction in the upper pharynx below the uvula for the uvular [q] and the emphatic coronals [$s^{ʕ}$, $t^{ʕ}$]. The constriction location is very similar to that of Arabic back vowels in Arabic vowel Factor 1. Retraction of the pharyngeal wall widens the cavity somewhat. Note that [q] and [$t^{ʕ}$] also have some narrowing of the lower pharynx as well through Factor 2. [ʕ, ħ] have negative weights on this factor, and thus have advancement of the rear dorsum in the upper pharynx, leaving a primary constriction at the pocket of the epiglottis from Factor 2.

Figure (5-14) shows the consonant space for the three-speaker solution. Factor 1 separates the coronals, shown on the right-hand side of the upper grid, from the non-coronals on the left. The second factor separates segments with a raised blade and front dorsum, epitomized by [k] at the top, from low, retracted tongue root segments, epitomized by [ʕ] at the bottom. [q, ħ, $t^{ʕ}$] are clearly grouped with [ʕ], while [$s^{ʕ}$] remains aligned with [s, t]. We can hypothesize that the aerodynamic constraints on [$s^{ʕ}$] preclude it from lowering tongue blade/front dorsum and thus retracting the tongue root too much. [$s^{ʕ}$] is more clearly separated from [s, t] by Factor 3. The main movement in

Factor 3 is a retraction of the rear dorsum into the upper pharynx. [q] weights this movement the most, followed by [tˤ, sˤ].

The pharyngeal consonants [ʕ, ħ] are similar but not identical in their use of factors. [ʕ] uses Factor 2 more than Factor 3 and does not use Factor 1 at all, while [ħ] uses similar amounts of all three factors. Because of Factor 1, [ħ] has additional raising of the dorsum under the palate, more raising of the larynx, advancement of the rear dorsum (widening the area just below the uvula), and retraction of the root in the laryngopharynx. [ħ] thus concentrates retraction in the lower pharynx, does not have constriction in the upper pharynx, and raises the dorsum. [ʕ] has more general retraction throughout the pharynx, although the constriction is greatest in the laryngopharynx. For both segments, the constriction is accomplished more by movement of the tongue root and elevation of the laryngeal structures than by movement of the pharyngeal wall. Both segments also display widening of the lip aperture, and thus most likely lowering of the jaw. In [ħ], the back of the tongue is cambered, as noted by Delattre (1971). It also displays more of the secondary narrowing of the anterior vocal tract noted by Ghazeli (1977). These two movements give [ħ] a pyramidal shape (see §1.2.1).

In summary, [ʕ, tˤ, ħ, q] display a general retraction of the rear dorsum and tongue root throughout the pharynx, accompanied by raising of the larynx, but retraction of the pharyngeal wall from Factor 2. [q, tˤ, sˤ] have additional backing in the upper pharynx from Factor 3, while movement in the upper pharynx is subtracted from [ʕ, ħ] by the same factor. Factor 1 contributes to raising of the dorsum under the soft palate for [q] and, in the opposite direction, retraction into the mid pharynx for all coronals.

5.5.3 Discussion and Comparison with Akan

Factor analyses of Akan and Arabic show retraction of the tongue root at the epiglottis for [-ATR] vowels in Akan and for pharyngeals and low vowels in Arabic, although there are differences in behavior in the laryngopharyngeal area. The Akan solution shows more movement of the pharyngeal wall and sub-epiglottal portion of the tongue, as well as raising and lowering of the larynx. This is not true of all ATR languages, as for example in Ateso, where larynx height does not vary (Lindau 1975). Thus we might consider the primary contrast between [±ATR] vowels to be the retraction at the epiglottis.

The Arabic vowel and consonant analyses provide a basis for analyzing the emphatic segments, both consonants and vowels, as uvularization with a primary constriction in the upper pharynx. Arabic consonant Factor 3 (5-13) for [q tˤ sˤ] shows retraction in the upper pharynx very clearly. The vowel evidence is not as definitive, but suggests that the relevant parameter for vowels is also retraction in the the upper pharynx. They would then all have an active dorsal articulator. However, there is a low component for some of these segments: [q] and [tˤ] are grouped with the low pharyngeals in Arabic consonant factor 2. There is thus the possibility that they use both dorsal and radical articulators.

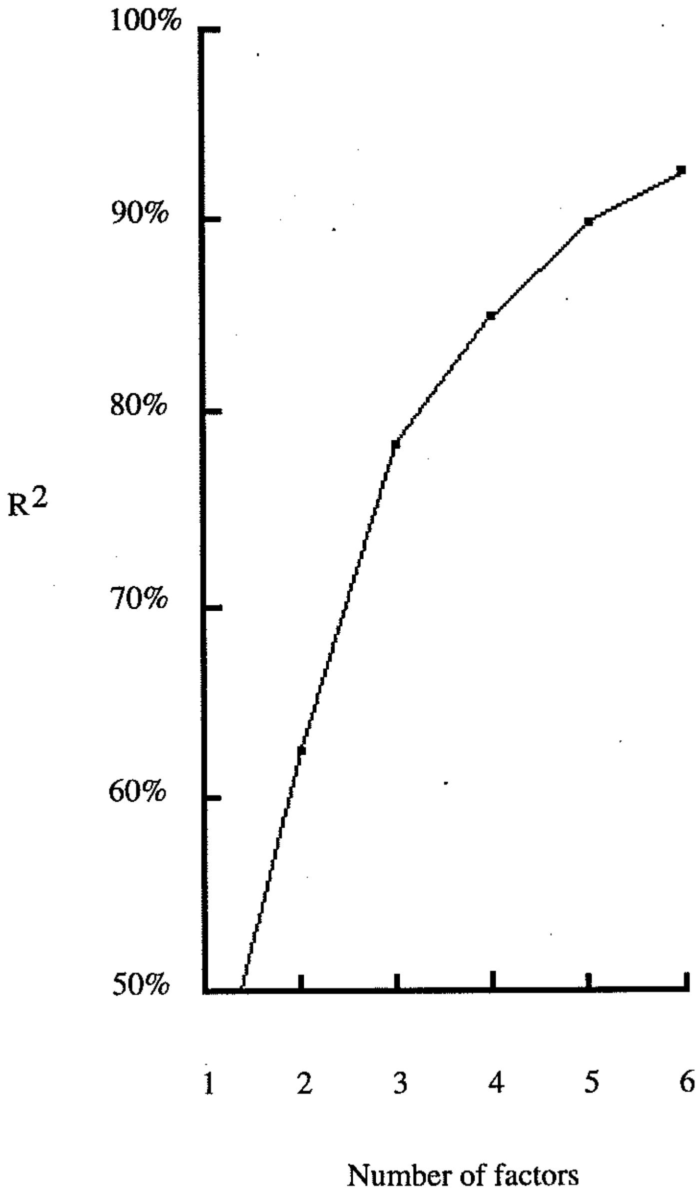
So far, this study provides a preliminary basis for a revised grouping of the segments with a constriction in the pharynx. In contrast with Ladefoged 1989, [-ATR] vowels are here grouped with pharyngeal consonants and the low vowel [ɑ]. Further analyses will be done of the Arabic consonant and vowel data in Chapter 7, and of two additional languages, Ndut and !Xóõ, in Chapter 6.

5.6 Other PARAFAC analyses

5.6.1 Solution for five speakers

5.6.1.1 Data and PARAFAC analysis

For the sake of comparison, the solution for five-speakers is presented below, although this solution is flawed by a moderately high correlation between the first two factors. The five speakers are one Tunisian (Ghazali no date), two Iraqi (Ali no date, Al-Ani 1970), and two Syrian (Ferguson and Abramson 1962). The R^2 values for different dimensionalities are plotted in (5-15). The sharpest break occurs at three factors, and in fact, solutions at higher dimensionalities were not unique as can be seen in (5-16). The between-factor correlations for Mode A (vocal tract profile) are given in (5-17).



(5-15) Percentage of variance (R^2) accounted for by *n* factors for Arabic consonants, solution for five speakers. R^2 for the one-factor solution is 35%.

(5-16) Summary of PARAFAC analyses for the Arabic consonant solution for five speakers

Number of factors	Converged (iterations in parentheses)	Unique	R^2	System variation	Correlation between factors
1	yes (39, 18, 19)	close	.33/.35	yes	n.a.
2	yes (247,134,134)	close	.63	yes	low
3	yes (433, 280, 284)	yes	.78	yes	mid (.57)
4	yes (444, 515) no (1000)	no	.89/.85	?	n.a.
5	yes (793, 993) no (1000)	no	.90/.89	?	n.a.
6	no (1000), yes (886, 744)	no	.93	yes	n.a.

(5-17) Between-factor correlations for Mode A; Arabic consonant solution for five speakers (third trial/run)

	Factor 1	Factor 2	Factor 3
Factor 1	1.000		
Factor 2	0.574	1.000	
Factor 3	0.032	-0.201	1.000

The correlation between the first and second factors is on the high side, and renders this solution somewhat suspect. However, after the solution for three speakers presented above, this was the next best solution. The Mode C (speaker) loadings for the five-speaker solution are given in (5-18).

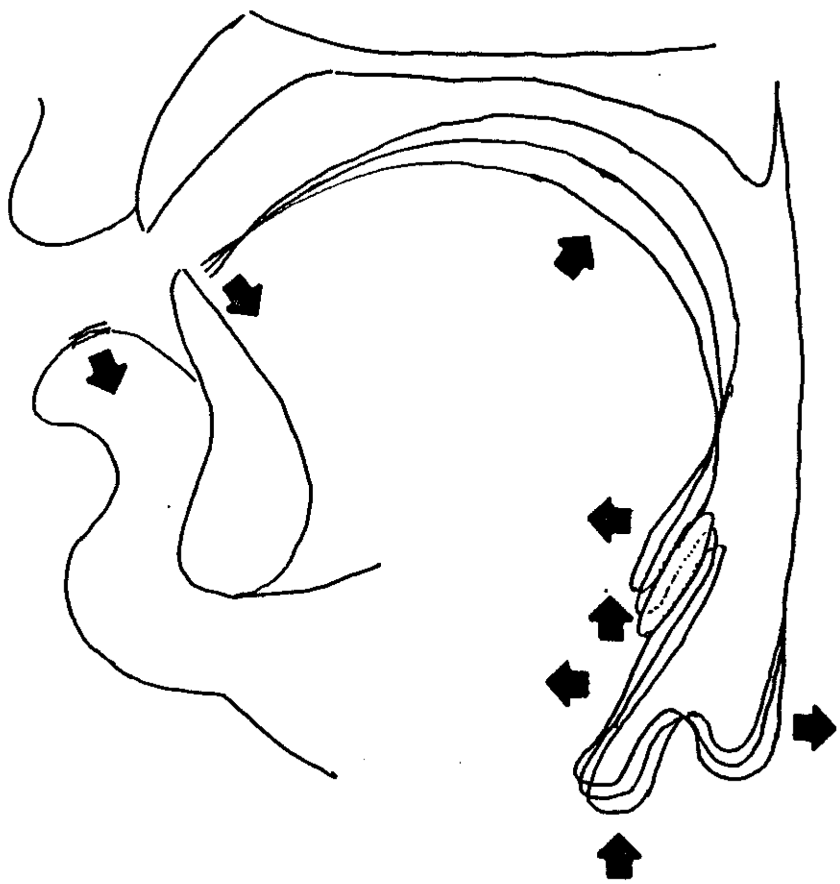
(5-18) Mode C (speaker) loadings for the Arabic consonant solution for five speakers (first trial/run)

	Factor 1	Factor 2	Factor 3
Ghazali	2.112	2.407	2.564
Ali	2.186	2.589	1.502
Syrian 1	4.842	1.610	2.580
Syrian 2	6.662	3.498	2.003
Al-Ani	2.437	2.522	1.819

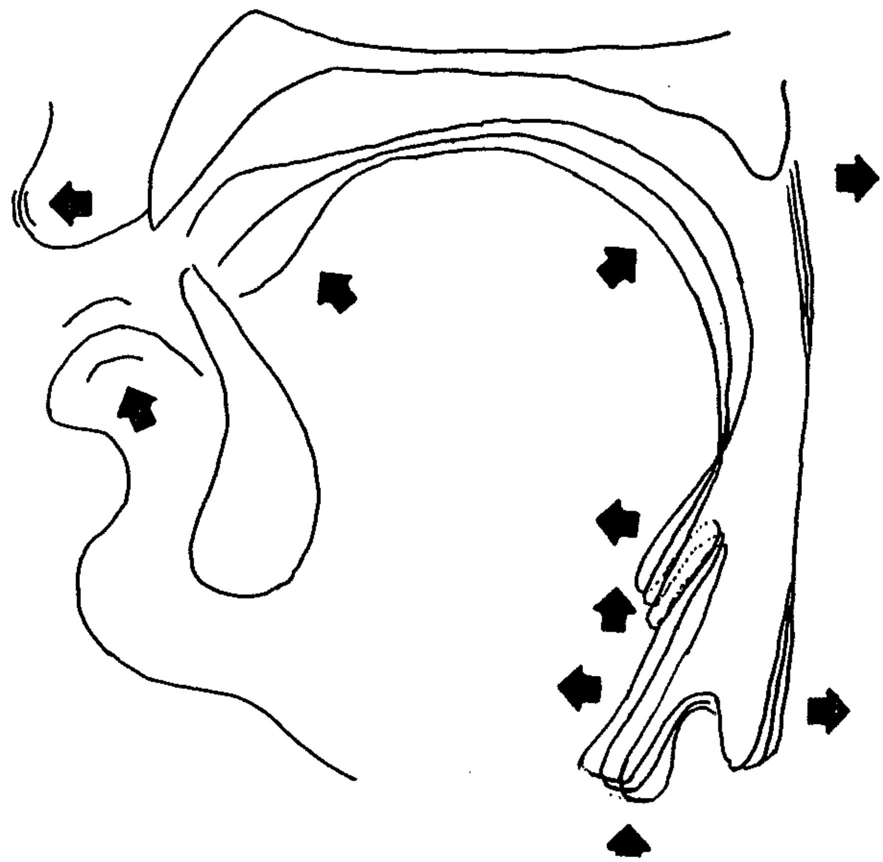
5.6.1.2 Discussion of the Arabic consonant solution for five speakers

In the first factor (5-19), the rear dorsum of the tongue is raised under the soft palate and the uvula, the tongue root is advanced and the larynx is raised. As can be seen in (5-22), a plot of the consonant space, this movement contributes most to [q, k]. The opposite movement segregates the coronals into one class. The pharyngeals rank zero on this factor. Both Syrian speakers (see (5-18)) load very highly on this factor.

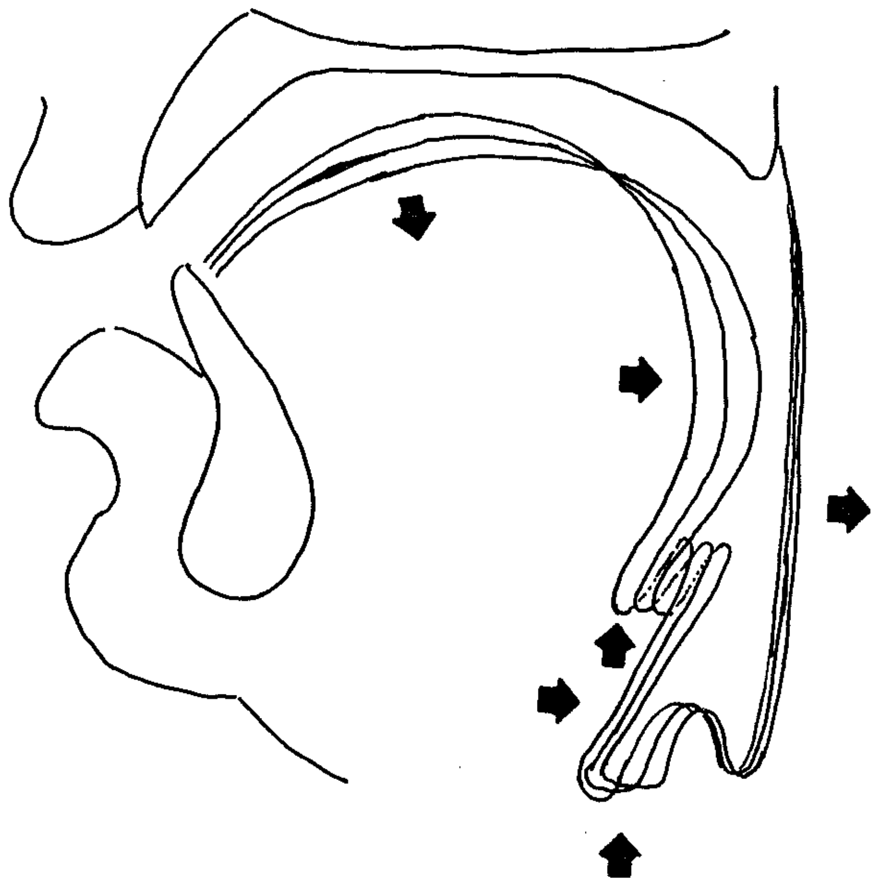
Factor 2 (5-20) forms the coronals with a high tongue tip and blade and high dorsum under the entire palate. The tongue root is advanced and the larynx is raised. The retracted alveolars rank slightly higher on this factor than do the plain alveolars. At the opposite end of the scale (see (5-22)) are the pharyngeals [ʕ, ħ] and the uvular [q]. The pharyngeals would thus have a low tongue body position, retracted tongue root and a lowered larynx. more retraction in the mid-pharynx. The constriction location for [ħ] is concentrated from the tip of the epiglottis down into the laryngopharynx, whereas this zone is longer and extends into the mid-pharynx for [ʕ]. For [q], the low tongue body profile from this factor would be offset by raising of the rear dorsum in Factors 1 and 3. In Factor 2, the cross-over point in the pharynx and the movement of the rear dorsum and tongue root are almost



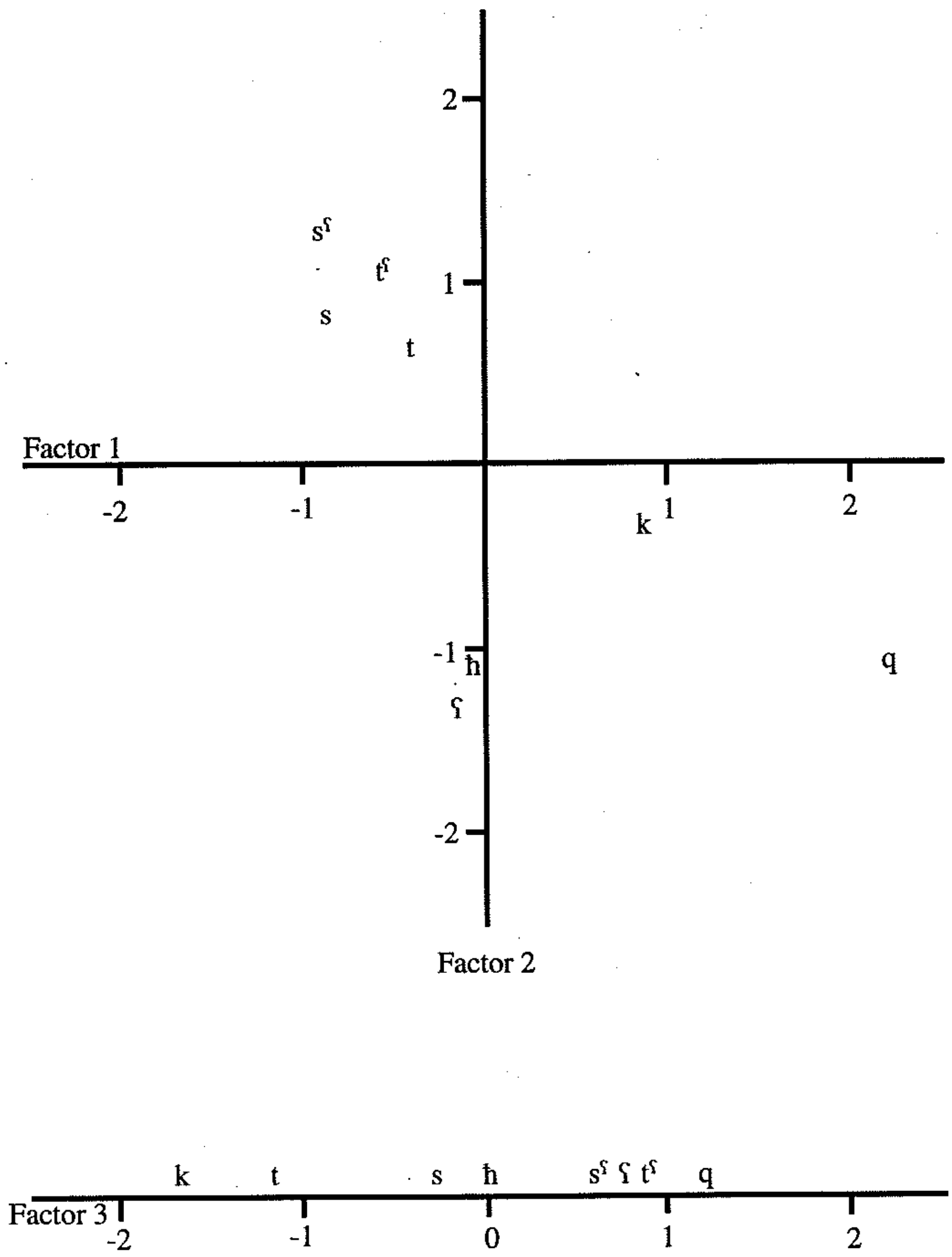
(5-19) Solution for five speakers: Arabic consonant Factor 1



(5-20) Solution for five speakers: Arabic consonant Factor 2



(5-21) Solution for five speakers: Arabic consonant Factor 3



(5-22) Solution for five speakers: Arabic consonant space identical with the first factor, accounting for the high between-factor correlation. The main difference is in the large movement of the tongue tip in this factor. The non-Syrian speakers (see (5-18)) load highest on Factor 2.

Factor 3 (5-21) displays a lowered front dorsum, large retraction of the rear dorsum into the upper pharynx, lesser retraction of the tongue root, slight raising of the larynx and retraction of the pharyngeal wall. As can be seen in (5-22), [q] ranks highest, followed by [tˤ, ʕ, sˤ], while [k, t, s] are on the opposite end of the scale with a wider pharynx and raised front dorsum. [ħ] is Ø.

To summarize, [q, k] are formed by the dorsal articulation in Factor 1, Factor 2 displays a high tongue profile for coronals versus a low tongue profile for pharyngeals, and retraction by both the rear dorsum and the tongue root in Factor 3 contributes to [q], retracted alveolars [tˤ, sˤ], and the pharyngeal [ʕ].

5.6.1.3 Comparison of Arabic three-speaker and five-speaker solutions

In order to compare this solution with the solution for three speakers presented above, correlations were run between the factor loadings in Mode A for the two solutions. These are given in (5-23):

(5-23) Correlations of Mode A factor loadings between solutions for three- and five-speakers

3-speaker solution:	Factor 1	Factor 2	Factor 3
5-speaker solution:			
Factor 1	-0.369	0.361	*0.521*
Factor 2	0.523	0.655	*0.577*
Factor 3	0.165	**-0.837**	*0.591*

Factor 3 (3-speaker solution) and Factor 2 (5-speaker solution) show the greatest similarity with an inverse correlation of -0.837 (in bold type). Factor 2 from the five-speaker solution (underlined) shows almost equal correlations with all three factors from the solution for three speakers. Likewise, Factor 3 from the three-speaker solution (in italics) shows almost equal correlations with all three factors from the solution for five speakers. These splits make a one-to-one comparison of factors rather difficult, so the information has been listed in (5-24), beginning with the two factors showing the highest correlation:

(5-24) Comparison of articulatory displacements between solutions for three- and five-speakers

Solution for five speakers	Solution for three speakers
Factor 3	Factor 2
front dorsum lowered, rear dorsum and tongue root retracted	front dorsum raised, rear dorsum and tongue root advanced
cross-over point higher	cross-over point lower
separates retracted & pharyngeal segments from [k, t, s]	almost separates retracted & pharyngeal segments (except [$s^ʕ$]; signs reversed)
Factor 2	Factor 1
tip & tongue body raised, dorsum retracted,	tip raised, tongue body slightly lowered
separates coronals from non-coronals	separates coronals from non-coronals
with [ʕ] at the opposite end of the spectrum	with [q] at the opposite end
fits retracted coronals better	fits [t] best

Factor 1

high dorsum under soft palate

separates coronals from [k, q]

Factor 3

dorsum retracted into upper pharynx

separates [q, $t^{ʕ}$, $s^{ʕ}$] from others

Solution for five speakers

pharyngeals

Factor 2: retraction at pocket, low dorsum, larynx lowered, lower pharyngeal wall advanced

Factor 3: retraction in entire pharynx for [ʕ], larynx raised, wall retracted

uvular stop [q]

Factor 1: raising under soft palate & uvula, larynx raised

Factor 3: retraction in mid-upper pharynx, larynx raised, wall retracted

Factor 2: similar movement as Factor 1, but ranks lower because of tip movement

retracted alveolars

Factor 2: tip raised, raising of rear dorsum under uvula, larynx raised

Factor 3: retraction primarily in upper pharynx, pharyngeal wall retracted, larynx lowered

Solution for three speakers

pharyngeals

Factor 2: retraction throughout pharynx,
larynx raised, wall retracted

Factor 3: advancement of rear dorsum in upper pharynx, additional retraction of epiglottis and sub-epiglottal tongue root

uvular stop [q]

Factor 1: raising under soft palate, larynx raised, tip low

Factor 3: retraction in upper pharynx closer to uvula, wall retracted

retracted alveolars

Factor 3: retraction in upper pharynx, larynx raised a bit

Below we will compare the two analyses by segment class:

Pharyngeal consonants [ħ, ʕ] in Arabic: In the analysis of three speakers of Arabic, these segments are formed by almost equal (and negative) amounts of Arabic (3) Factors 2 (5-12) and 3 (5-13). In the solution for five speakers of Arabic, [ħ] is modeled solely by Arabic (5) Factor 2 (5-20) (negatively), and [ʕ] is modeled by both Arabic (5) Factors 2 (5-20) (negatively) and 3 (5-21). Negative loadings on a factor reflect movements in the opposite direction of the arrows. Use of factors is graphed in (5-14) and (5-22). In both data sets, the second factors, (5-12) and (5-20), display an even degree of constriction from the tip of the epiglottis to the larynx. The blade and dorsum are lowered in both factors. Both factors widen the lip aperture, so we infer that the jaw is lowered. The tongue root movements of the Arabic (3) Factor 2 (5-12) and the Arabic (5) Factor 2 (5-20) are quite similar. In the latter case, movement is restricted to just tongue root movement (from the tip of the epiglottis down), while in the former case, there is also some retraction of the rear dorsum. Movement of the tongue root is similar to that found in (4-7) for [-ATR] vowels in Akan and (5-6) for [æ, ɑ] in Arabic, but the pharyngeal consonants show less overall movement of the tongue root and less movement in the mid pharynx above the tip of the epiglottis. In fact, both Arabic (3) Factor 3 (5-13) and Arabic (5) Factor 3 (5-21), actively advance the rear dorsum in the production of the pharyngeal consonants. This helps produce a pyramidal shape plus sulcalization of the dorsum (noted by Ghazeli, 1977 and Delattre, 1971). The main difference in the production of the pharyngeals modeled by these two analyses is in the behavior of the larynx: raised for both pharyngeal segments in the three-speaker data set, but lowered for [ħ] and neutral for [ʕ] in the 5-speaker analysis. Due to the larger amount of missing data in the Arabic (5) data set, we regard the Arabic (3) data sets results to be better. The pharyngeal wall does not contribute to constricting the pharynx in Arabic (3) data set as there are almost equal contradictory movements of the pharyngeal wall in Factors 2 and 3. In Arabic (5) Factor 2 (5-12), the lower pharyngeal wall contributes slightly to the constriction. Arabic (5) Factor 3 (5-21) increases the laryngopharyngeal constriction for [ʕ], raises the larynx, countering Arabic (5) Factor 2, and extends the area of constriction into the mid pharynx.

For the pharyngeal consonants, the active articulator is the tongue root. The production of pharyngeal consonants involves both a constriction against the back wall of the pharynx as well as one between the tubercle of the epiglottis and the upper structures of the larynx. The constriction begins at the level of the pocket of the epiglottis and continues down to the larynx.

Uvular stop [q] in Arabic: In both Arabic consonant solutions, [q] loads highly on two different factors: one which displays raising under the soft palate (in both cases, the first factor-(5-11) and (5-19)) and one which shows retraction in the upper pharynx below the uvula (the third factor in both cases (5-13) and (5-21)). (Relative weights of factors are graphed in (5-14) and (5-22).) Retraction of the rear dorsum into the upper pharynx is accompanied by retraction of the rear wall of the pharynx in both instances (causing widening of the pharyngeal airspace). The larynx is raised by both factors in both data sets. Lip aperture is widened more in the Arabic (3) data set than in the Arabic (5) data set. In the five-speaker data set, [q] also uses Arabic (5) Factor 2 to lower the tip and blade.

Emphatic coronals /tˤ, sˤ/ in Arabic: In both of the PARAFAC Arabic consonant solutions, these two segments load highest on the factor which displays retraction of the rear dorsum in the upper pharynx under the uvula (the third factor in both solutions, (5-13) and (5-21)). In the solution for three speakers, the (secondary) constriction location is slightly closer to the uvula than that in the solution for five speakers.

In the three-speaker analysis, the retracted coronals and /q/ are modeled by Factor 3 (5-13), which displays a constriction in the mid-pharynx between the uvula and the tip of the epiglottis (see (5-14)). All coronals in the three-speaker data set use Factor 1 (5-11) to raise the tip and blade of the tongue. In the five-speaker analysis, the retracted coronals are modeled by a positive amount of Arabic (5) Factor 2 (5-20), which raises both the front and rear dorsum, a negative amount of Arabic (5) Factor 1 (5-19), which subtracts constriction under the soft palate and uvula, and a positive amount of Arabic (5) Factor 3 (5-21), which adds a constriction in the mid-pharynx (see (5-12)). Lip aperture is narrowed, the pharyngeal wall is moved rearward (widening the airspace), raising of the larynx in Arabic (5) Factors 2 and 3 is diluted by lowering in Arabic (5) Factor 1.

In summary, the pharyngeal segments [ʕ, ħ] from both solutions display retraction primarily at the pocket of the epiglottis, raising of the larynx and a constricted laryngopharynx. In both solutions, [ʕ] shows advancement of the rear dorsum in the upper pharynx. The uvular stop [q] displays raising of the dorsum under the soft palate and retraction of the rear dorsum into the upper pharynx in both solutions. The retracted alveolars [sˤ, tˤ] are presented more economically in the solution for three speakers using one factor with retraction in the upper pharynx above the tip of the epiglottis. In the solution for five speakers, two factors contribute to these segments. One is similar to the solution for three speakers in that the rear dorsum is retracted into the upper pharynx, but in this factor this movement is conflated with tip raising necessary for all of the alveolars. A second factor adds retraction throughout the pharynx from the uvula to the larynx. The two solutions are not that dissimilar in how the different linguistic categories of segments are analyzed, although the factors divide the factor space differently. The solution for three speakers better meets the criteria for a successful PARAFAC analysis and should be taken as the best indicator of the factor space for Arabic consonants. The solution for five speakers has a fairly large amount of missing data, and it is comforting to know that despite that, it is still quite similar to the solution for three speakers.

5.6.2 Covariance analysis of consonants and vowels for four speakers

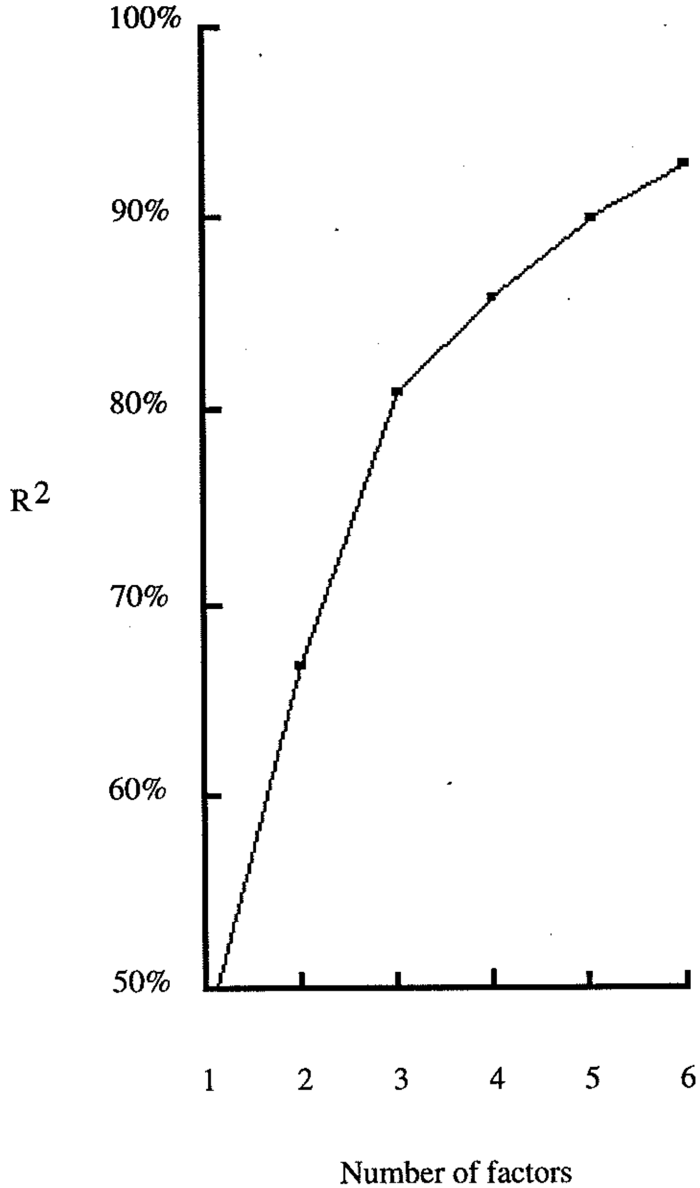
5.6.2.1 Data and PARAFAC analyses

In Chapter 7, we will present a pooled PARAFAC analysis of all the language data using covariance matrices. The great advantage to using covariance matrices is that it eliminates the need to keep the segments in Mode B identical, so one can analyze data with different segment inventories. Below we will show the factor space arising from the analysis of four speakers of Arabic in which data from both consonant and vowel segments are used, and any segments with more than a few points of missing data are eliminated. In (5-25), the speakers and segments used for this analysis are listed. These are the same data used in Chapter 7 as part of the pooled analysis.

(5-25) Data sources for covariance analysis of Arabic consonants and vowels

Ghazali (Appendix A, IIa)	s sˤ t tˤ k q ħ ʕ i iˤ æ ɑ u uˤ
Metoui (1989)	i iˤ æ ɑ u uˤ
Bukshaisha (1985)	s sˤ ħ ʕ
Ali (Appendix A, IIb)	s sˤ t tˤ k q i iˤ æ ɑ u

The R^2 values for different dimensionalities are plotted in (5-26). The sharpest break occurs at three factors. (5-27) summarizes the results of PARAFAC analyses in terms of the criteria outlined in §3.4. After three factors, between-factor correlations start to rise (the highest between-factor correlation for the four factor solution is 0.516, and the highest for the five-factor solution is -0.576). Both the R^2 curve and the between-factor correlations direct us to select the three-factor solution as the most appropriate. The three factors generated by the three-factor solution are retained in the four-factor solution. The only drawback to the selection of the three-factor solution is that the fourth factor displays movement specifically by the rear dorsum which is otherwise not apparent in the three-factor solution. As we are analyzing covariance matrices, we cannot evaluate how the different order factor solutions perform in the segment space. The Mode C loadings for the three-factor solution are given in (5-28). As the inventories of each speaker are rather different, we can make hypotheses about which classes of segments are being fit by the different factors.



(5-26) Percentage of variance (R^2) accounted for by *n* factors for PARAFAC analysis using covariance matrices of Arabic vowels and consonants.

(5-27) Summary of PARAFAC analyses for the Arabic covariance three-factor solution

Number of factors	Converged (iterations in parentheses)	Unique	R^2	System variation	Correlation between factors
1	yes (10, 11, 12)	yes	.47	yes	n.a.
2	yes (10, 19, 13)	no	.67/.61	yes	low
3	yes (16, 23, 12)	yes	.81	yes	low
4	yes (46, 59, 91)	yes	.86	yes	low-mid
5	yes (45, 53, 67)	yes	.90	yes	mid
6	yes (80, 78, 57)	yes	.93	yes	

(5-28) Mode C loadings for the three-factor solution

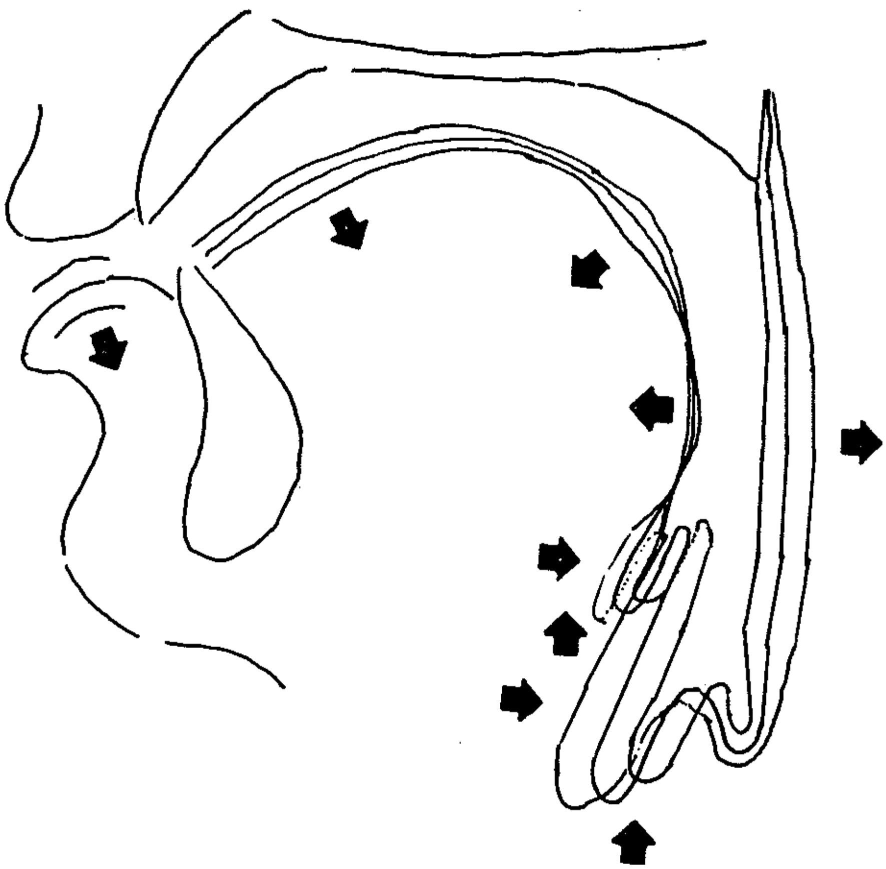
	Factor 1	Factor 2	Factor 3
Ghazali	0.8653	2.739	0.2074
Metoui	0.2210	0.3489E-01	2.943
Bukshaisha	2.659	0.7696E-01	0.3252
Ali	0.2546	1.149	0.5248

5.6.2.2 Discussion of the combined consonant and vowel solution for four speakers

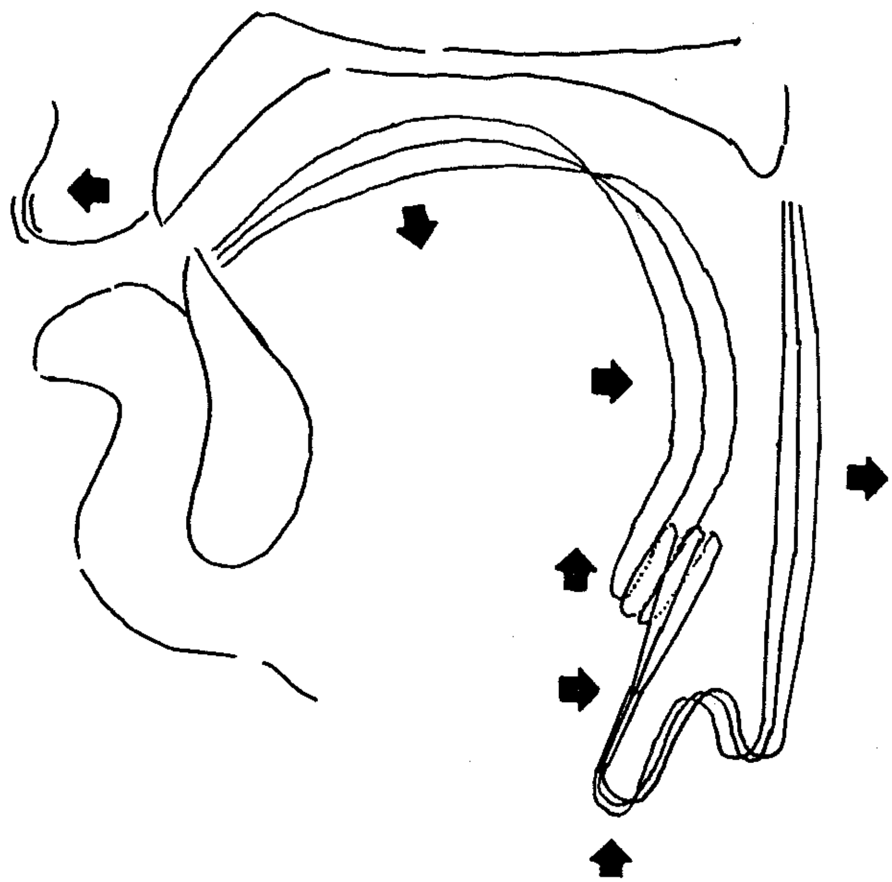
Figure (5-29) displays the articulatory movements generated by the first factor. The largest movements are in the pharynx. The tongue root is retracted from the tip of the epiglottis all the way down to the larynx, which is raised, and the pharyngeal wall is retracted, offsetting the retraction of the tongue root. At the same time, the entire dorsum is depressed, but to a lesser extent, and the lip aperture is widened. From (5-28) we can see that Bukshaisha, whose inventory contains only consonants, loads the heaviest on this factor, followed by Ghazali, whose inventory is half consonants and half vowels. The movements in this factor are most similar to those of Factor 2 (5-20) in the consonant solution for five speakers, minus the tip movement. In the five-speaker consonant solution, the low pharyngeal movements model the segments [ʕ, q, ħ], which is most likely the case here. Raising of the dorsum would contribute to the coronals.

The movements generated by Factor 2 are shown in (5-30). In this factor, the front dorsum is lowered as the rear dorsum and tongue root are retracted down to the level of the pocket of the epiglottis. There are slight movements below the pocket, and the larynx is slightly raised. The pharyngeal wall is substantially retracted. Ghazali and Ali, both of whom have both consonants and vowels in their segment inventories, have their highest loadings on this factor. Somewhat disconcerting is the fact that Metoui and Bukshaisha have $\emptyset$ loadings on this factor. However, given the diversity of inventories perhaps one couldn't expect each factor to model movements useful to all speakers. This factor shows similarities to vowel Factor 1 (5-5) and to Factor 3 (5-21) of the consonant solution for five speakers. Vowel Factor 1 separates front vowels from back vowels, while consonant Factor 3 of the solution for five speakers separates segments with a pharyngeal component ([q, $t^ʕ$, ʕ, $s^ʕ$]) from [k, t, s]. Thus we can infer that with this factor the PARAFAC solution models both consonants and vowels: consonants with a pharyngeal component are combined with back vowels.

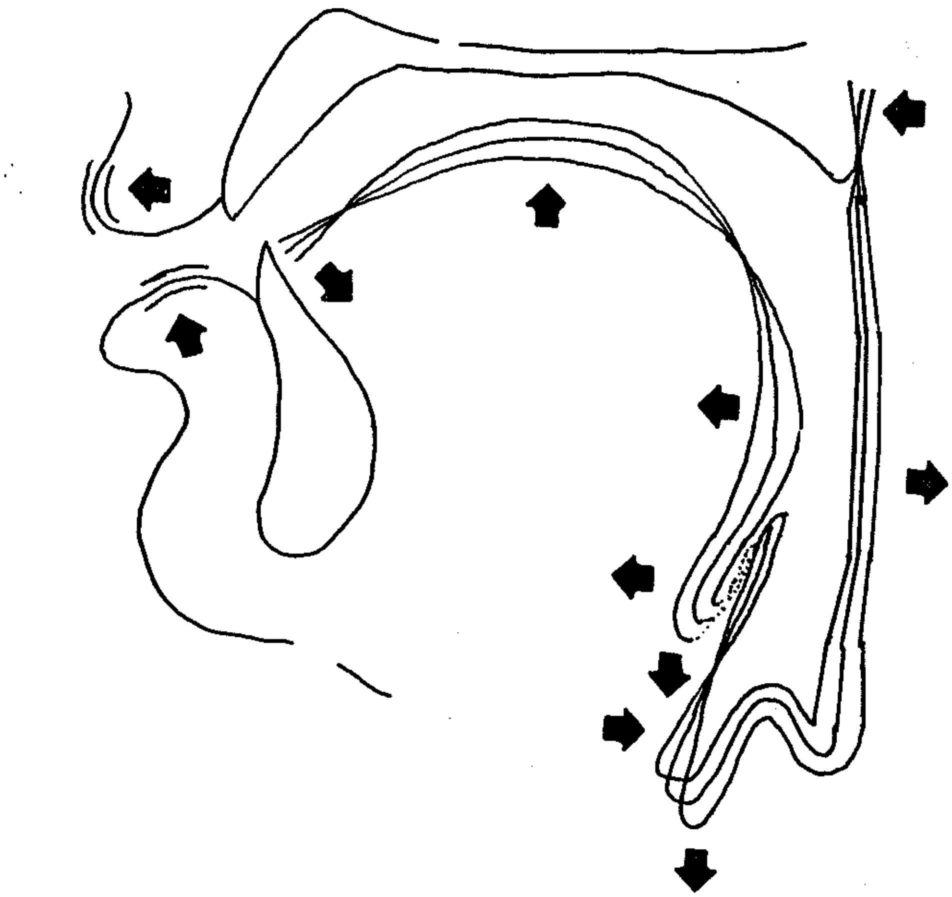
In the third factor (5-31), the cross-over point on the dorsum has shifted further back to a position under the uvula. As the front dorsum is raised, the rear dorsum and tongue root, to the level of the pocket of the epiglottis, are advanced. The larynx is lowered and the pharyngeal wall is retracted, creating an expanded pharynx. Metoui, whose inventory consists solely of vowels, loads highest on this factor, while the others have fairly low loadings. It is fairly similar to vowel Factor 2 (5-6), except for the direction of movement



(5-29) Arabic consonant and vowel Factor 1 (from analysis of covariance matrices)



(5-30) Arabic consonant and vowel Factor 2 (from analysis of covariance matrices)



(5-31) Arabic consonant and vowel Factor 3 (from analysis of covariance matrices)

of the pharyngeal wall. This factor separated the low vowels [æ, ɑ] from the others. It also shows some similarity to consonant Factor 2 (5-12) from the solution for three speakers, which separates low and/or back segments [ʕ, tˤ, ħ, q] from non-low, non-back segments.

We cannot say for certain how these factors would model the different segments or how different linguistic categories would be treated. The data above were presented in order to see how a combined analysis of consonants and vowels would compare with analyses of consonants and vowels performed separately and also to understand how PARAFAC would treat the data that will be used in the pooled analysis in Chapter 7, as we are not using exactly the same sets of data as in the consonant or vowel solutions presented above. It is reassuring to find that the three factors of the combined consonant and vowel solution show close similarities to factors of the individual consonant and vowel analyses.

5.7 Comparison of factor analyses with previous studies of Arabic

5.7.1 Pharyngeals [ʕ, ħ]

In our discussion of the pharyngeal segments, we will be referring to the Arabic consonant solutions for three (§ 5.5) and five (§ 5.6.1) speakers, and to the discussion in §1.2.1 of descriptions of these segments in the literature. In this section we wish to explore questions regarding the nature and location of the constriction for these segments, and the degree to which various pharyngeal structures are involved in their production.

Two important questions concern identifying the active articulator and the location. Is the active articulator the epiglottis (Ladefoged 1982:149) or the tongue root or even the base of the epiglottis? Is the main constriction against the back wall of the pharynx (Ladefoged 1982:149) at the level of the epiglottis (Ghazeli 1977:37, Laufer & Baer 1988:190) or against the upper structures of the larynx or both?

Both of the Arabic consonant solutions (for three speakers and for five speakers) display retraction of the tongue root from the tip of the epiglottis down to the larynx. In addition, the solution for three speakers shows the larynx to be raised, further constricting the laryngopharynx. With the addition of two Syrian speakers in the solution for five speakers, the larynx is lowered for both segments in one factor, but raised again for [ʕ] in another. In neither case does the epiglottis seem to be playing an independent role; rather, it seems to be pushed along with the tongue root. Earlier studies (Gairdner 1925:27, Al-Ani 1970:60, El-Halees (1985:288) suggest that the epiglottis is lowered; here we have found that the upper structures of the larynx are raised while the epiglottis is backed along with the tongue root, which is more similar to the description in Ghazeli (1977:49). Thus we would have to say that the active articulator is the tongue root and that the production of pharyngeal consonants involves both a constriction against the back wall of the pharynx as well as one between the base of the epiglottis and the upper structures of the larynx. The constriction begins at the level of the pocket of the epiglottis and continues down to the larynx.

Ghazeli (1977:36-7) found forward displacement of the lower end of the back wall of the pharynx. In both PARAFAC analyses, the pharyngeal wall seems to be retracted rather than advanced on the balance; there does not seem to be a coordinated gesture between the various pharyngeal structures to either constrict or expand the pharynx as in Akan. In the solution for three speakers, the entire length of the dorsal pharyngeal wall is displaced rearward, and this is true for [ʕ] but not for [ħ] in the solution for five speakers.

Delattre (1971) found differences in the location of the pharyngeal stricture for these two segments in Lebanese Arabic, namely that the stricture for [ħ] was lower than the stricture for [ʕ]. In our solutions for both three and five speakers, we found a more general retraction of the dorsum and tongue root for [ʕ] throughout the pharynx, while [ħ] displayed retraction only at the level of the epiglottis and lower. For [ħ], the rear dorsum is advanced and the front dorsum under the palate is slightly raised.

Ghazeli (1977:37) found the shape of the tongue to be pyramidal, and Delattre (1971:134) also found the front dorsum to be raised. In the solution for three speakers, use of Factor 1 by [ħ] but not [ʕ], gives [ħ] additional raising of the dorsum under the palate and widening of the upper pharynx. It thus also corresponds to the descriptions by Delattre (1971) that the back of the tongue is cambered in [ħ] and by Ghazeli (1977), who noted a secondary narrowing of the anterior vocal tract. The differences between [ħ] and [ʕ] in our results show that Delattre's and Ghazeli's observations hold true of a wider geographical area.

5.7.2 Uvular stop [q]

In both Arabic consonant solutions, [q] loads highly on two different factors: one which displays raising under the soft palate (in both cases, the first factor) and one which shows retraction in the upper pharynx below the uvula (the third factor in both cases). Retraction of the rear dorsum into the upper pharynx is accompanied by retraction of the rear wall of the pharynx in both instances (causing widening of the pharyngeal airspace).

5.7.3 Retracted alveolars [$t^ʕ$, $s^ʕ$]

Our discussion in §1.2.3 focussed on the debate in the literature as to whether these segments are velarized, uvularized or pharyngealized, or whether different backing strategies are used by different dialects. In both of the PARAFAC Arabic consonant solutions, these two segments load highest on the factor which displays retraction of the rear dorsum in the upper pharynx under the uvula (the third factor in both solutions). In the solution for three speakers, the (secondary) constriction location is slightly closer to the uvula than that in the solution for five speakers. In both cases we would have to say that the backing is accomplished by uvularization rather than by pharyngealization for these speakers.

5.7.4 Retracted (emphatic) vowels [iˤ, ɑ, uˤ]

The literature reports these vowels to be sometimes lowered, sometimes backed, sometimes lowered and backed, or sometimes centralized from their non-emphatic counterparts (see §1.2.4 and § 5.2). The PARAFAC analysis of three speakers (§ 5.4) did not isolate a single factor which would compartmentalize the vowels in emphatic contexts from those in non-emphatic contexts, although it did indicate relative differences. All three emphatic vowels were shown to have more retraction of the rear dorsum than their non-emphatic counterparts. The location of the greatest degree of retraction is in the upper pharynx under the uvula, similar to the retraction found in emphatic coronals. In addition, [uˤ] and [ɑ] were shown to have retraction of the tongue root. Thus it would seem that we have found backing for [iˤ], and backing plus lowering for [ɑ, uˤ].

5.8 Summary of the chapter

In this chapter, we have presented one PARAFAC analysis of Arabic vowels, two analyses of Arabic consonants, and one combined consonant/vowel analysis. From these different analyses, we have gained a fairly unified picture of stricture locations of different pharyngeal segments, and of the behavior of the larynx and the dorsal pharyngeal wall. The pharyngeals show compression of the sub-epiglottal area and retraction at the tongue root, while the emphatic coronals and affected vowels display retraction of the tongue dorsum under the uvula in the upper pharynx. The dorsal wall of the pharynx does not move inwards during these segments to further constrict the pharyngeal airspace as in

Akan [-ATR] vowels. The larynx is raised (in the solution for three speakers) during production of the pharyngeal consonants, further constricting the laryngopharynx. The emphatic segments display less raising of the larynx.

In the next chapter, we will turn to the languages Ndut and !Xóõ. The first is a language with [ATR] vowel harmony, and the second, a language which shows degrees of pharyngealization upon vowels.

CHAPTER 6 OTHER LANGUAGES: Ndut and !Xóõ

6.0 Introduction

This chapter groups together languages with data from too few speakers to allow the use of PARAFAC individually. Potentially this group included Ndut, !Xóõ, Bzyb, Dargi, and Ubykh (see (3-1)). Unfortunately, all of the Caucasian languages (Bzyb, Dargi and Ubykh) had to be eliminated either due to the poor quality of the tracings or for lack of a sufficient number of targeted segments.

Using a technique explored in Jackson (1988a), data from the remaining languages were analyzed by first computing covariance matrices of $N_{measures}$ by $N_{measures}$. This allows the use of PARAFAC, but has the disadvantage of eliminating the segment mode. The output of a PARAFAC analysis using this technique consists of articulatory loadings and speaker loadings. Thus we can still plot articulatory displacements generated by each factor and we are able to tell the degree to which each speaker uses a given factor.

6.1 Ndut

Ndut is a Niger-Kordofanian language which belongs to the West Atlantic branch of the Niger-Congo sub-family (Greenberg (1963), Bennet & Sterk (1977)) and is spoken in Senegal. It has nine short vowels and nine long vowels. Gueye (1986) illustrates minimal and near minimal pairs (in which more than one vowel differs due to vowel harmony) for all vowels. The vowels are shown in (6-1) below (Gueye 1986:139):

(6-1) Ndut vowel phonemes

	Set 1 [+ATR]			Set 2 [-ATR]			
short	i		u	ɪ		ʊ	high
	e			ɛ		ɔ	mid
		ə			a		low
long	iː		uː	ɪː		ʊː	high
	eː			ɛː		ɔː	mid
		əː			aː		low

Ndut is unusual in that it has low [+ATR] vowels [ə, əː], but not the mid [+ATR] vowels [o, oː]. Gueye (1986:241) made seven measurements of the width of the pharynx between the uvula and the epiglottis from mid-sagittal x-rays for each vowel. In all cases, the two sets show the greatest divergence for the three lowest measurements, that is, those just above the epiglottis. [ə, əː] pattern with the rest of the [+ATR] vowels. Gueye (1986) provides mid-sagittal x-rays of all vowels for one speaker.

6.2 !Xóõ

!Xóõ is a Khoisan language spoken in Botswana and Namibia. Phonetically it is a very rich language, with four tones, five clicks and sixteen accompaniments (which add up to eighty distinct click consonants), eight other consonants, and five basic vowel qualities, which may be underlyingly normally voiced, nasalized, breathy voiced, glottalized, pharyngealized, and combinations of these (Traill 1981a, 1985). Of special interest to us are the pharyngealized vowels and what Traill (1981a:78) refers to as "strident vowels". The sets of vowels which we will analyze are the plain, pharyngealized and strident, as shown in (6-2). Traill (1981a) uses the symbol [̰] to mark the pharyngealized vowels, which has been changed here to [ˤ]. Strident vowels, transcribed here with an epiglottal fricative symbol [ʢ] after the vowel, are analyzed by Traill as representing the combination of breathy voice and pharyngealization for which he uses the symbols [̰] + [h]. Only back vowels occur in the latter two sets.

(6-2) Subset of !Xóõ vowels

plain vowels		pharyngealized	strident	
i	u	uˤ	uʢ	high
e	o	oˤ	oʢ	mid
	ɑ	ɑˤ	ɑʢ	low

In all sets, the distinction between the high and mid back vowels may be neutralized in many cases, phonetically yielding [ʊ, ʊˤ, ʊʢ] (Traill (1981a) [ʉ, ʉ̰, ʉ̰h]) for the sets in (6-2). Plain /ɑ/ is a central low vowel, but phonologically falls with the other back vowels. The blade of the tongue is in roughly the same position for pharyngealized vowels as for /ɑ/, but the root of the tongue is retracted at the epiglottis, stretching the tongue body between the blade and the root (See Appendix B). During production of the strident vowels the body of the tongue is lowered and the tongue root is retracted still further into the pharynx. The tip of the epiglottis vibrates against the back wall of the pharynx as a result of vibration of the arytenoid cartilages against the cushion of the epiglottis (Traill 1981a:78). The airway between the cushion of the epiglottis and the tip of the cartilages is extremely constricted, and the false vocal cords (ventricular bands) are adducted.

Traill (1981a:84) analyzes the strident vowels in !Xóõ as phonologically pharyngealized and breathy for parsimony as well as for distributional and phonetic reasons. We will discuss the three phonetic factors first. Although the precise mechanism of production differs between true breathy vowels (made with the vocal cords) and strident vowels (made with the ventricular bands), they share two phonetic properties: "acoustically the strident vowels are as noisy as are breathy voiced vowels, and aerodynamically strident vowels and breathy voiced vowels have greater airflow than vowels with normal voicing" (Traill 1981a:84). Thirdly, the strident vowels involve a constriction of the pharynx, although it is lower than that of the pharyngealized vowels. While there are similarities with both the pharyngealized and the breathy vowels, more so than with other groups, it should be kept in mind that articulatorily they are rather different: the constriction is in the laryngopharynx and the phonation is ventricular. The latter is made clear by this description (Traill 1981a:78): "The well-known purse-string effect of the contraction of the aryepiglottic muscle and its extension, the transverse arytenoid muscle, pulls the tips of the arytenoid cartilages together and upwards and adducts the false vocal cords. If a sustained pulmonic airstream blows the sphincter open, the result will be the 'phonation type' for the vowels ṵh, a̰h." [uʢ, ɑʢ]

Distributionally, the main reason for analyzing the strident vowels as pharyngealized + breathy is that the features nasalized, pharyngealized, glottalized and breathy combine quite freely. Not analyzing the strident vowels as pharyngealized + breathy would result in a gap in the distribution of these features. Even if we agree with the phonological analysis of the strident vowels as pharyngealized + breathy, phonetically they are worth a closer examination because of the unusually low pharyngeal constriction.

X-ray films were taken by Tony Traill of two speakers of !Xóõ in 1972 and 1975. He kindly lent me his films and I made tracings following the procedure described in

§3.4. Since the segment mode will be dropped during analysis of covariance matrices, there was no need to keep the set of segments identical for each speaker. For each speaker, tracings were made of the five plain vowels, three pharyngealized vowels, and two of the strident vowels ([u̢ˤ, ɑ̢ˤ]). Speaker 1 has an additional segment [ʊ], and speaker 2 has the neutralized [ʊˤ] in place of [oˤ].

6.3 PARAFAC analysis of Ndut and !Xóõ

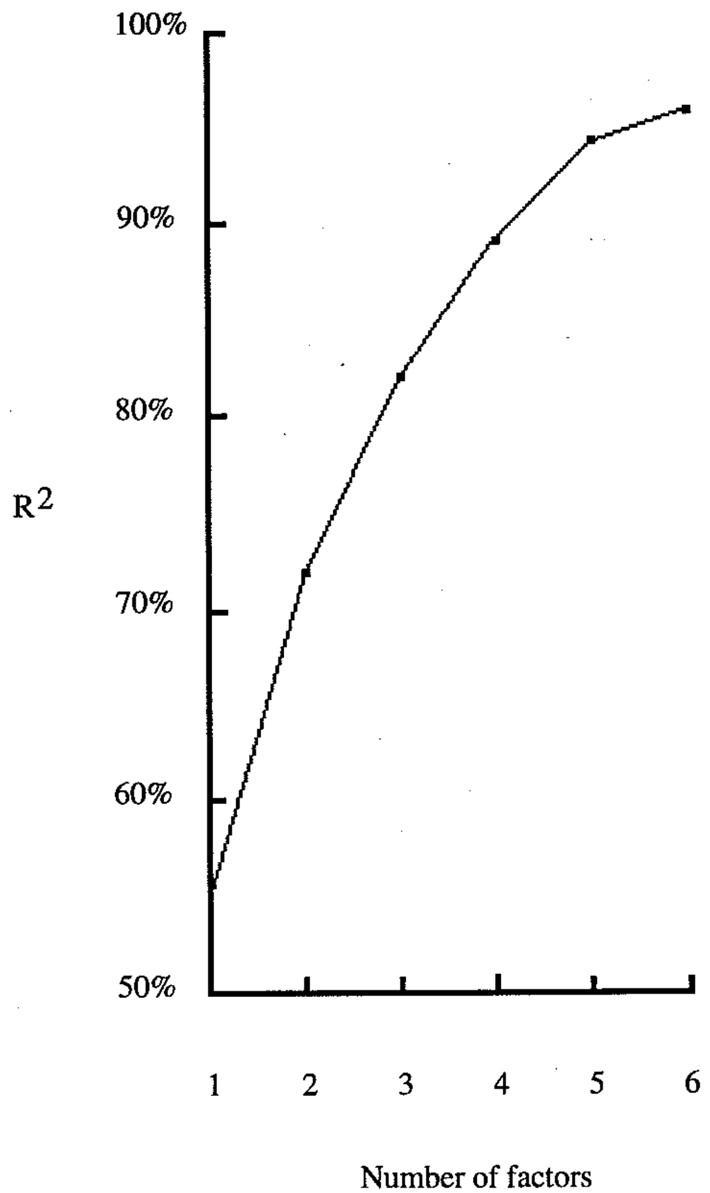
Data from the three speakers described above were analyzed jointly. The data set for the Ndut speaker contains eighteen vowels, nine short and nine long, or 540 data points. Of these, thirty-four points (6%) had missing values. Most of these points are distributed randomly, but eleven cases concern the height of the larynx. In these eleven cases, the top of the arytenoid cartilages is visible, but the larynx itself has descended below the frame of the x-ray. In the other cases where the larynx is visible, the distance from the top of the arytenoid cartilages to the larynx varied from 16-20 mm., with the average being 18.5 mm. This average of 18.5 was added to the measured height of the top of the arytenoid cartilages in those cases where the larynx itself was not visible as an estimate for PARAFAC. The data set for !Xóõ speaker 1 contains eleven vowels or 330 data points while the data set for !Xóõ speaker 2 contains ten vowels or 300 data points. !Xóõ speaker 1 had missing values for 30 points (9%), twenty-two of which were for the lip measurements, as the lips were not visible on the x-rays for this speaker. Lip measurements from !Xóõ speaker 2 were rescaled and used as estimates for the PARAFAC program. The data for !Xóõ speaker 2 had thirteen missing data points (4%). Estimates for these points, the remaining eight points for !Xóõ speaker 1, and the remaining twenty-three points for Ndut, were made in the same way as for Akan.

(6-3) summarizes the results of PARAFAC analyses in terms of the criteria outlined in §3.4. Solutions for one to six factors converged, and all were unique or quite close (the five-factor solution was close). It is difficult to select the appropriate number of dimensions in this data based on the improvement of fit (R^2, the percentage of variance accounted for), for as seen in (6-4), there are no sharp bends in the fit curve.

(6-3) Summary of PARAFAC analyses of Ndut and !Xóõ vowels (using covariance matrices)

Number of factors	Converged (iterations in parentheses)	Unique	R^2	System variation	Correlation between factors
1	yes (7, 10, 8)	yes	.56	yes	n.a.
2	yes (18, 17, 16)	yes	.72	yes	low
3	yes (25, 17, 45)	yes	.82	yes	low
4	yes (31, 43, 22)	yes	.89	yes	low
5	no (400), yes (58, 115)	close	.94	yes	
6	yes (144, 226, 191)	yes	.96	yes	

The improvement in fit between the five- and six-factor solutions is negligible, while there is still large improvement between the four- and five-factor solutions. However, since the five-factor solution had difficulty converging and did not generate a unique solution, the four-factor solution would seem to be the optimum one. It is worth considering the three-factor solution for a moment, though, as our analyses of Akan and Arabic had no more than three factors.



(6-4) Percentage of variance (R^2) accounted for by *n* factors for Ndut/!Xóõ

The first three factors of the three- and four-factor solutions are quite similar, although the order of the first two factors is reversed between the two solutions. The Mode C (speaker) loadings for the four-factor solution are given in (6-5). With the first three factors, there is one factor shared by all three speakers, a !Xóõ factor which fits !Xóõ speaker 2 more than !Xóõ speaker 1, and an Ndut factor. The additional fourth factor is also a !Xóõ factor, and fits the !Xóõ speaker 1 better. The movements generated by the four-factor solution are smoother, i.e. more uniform along contiguous points of the vocal tract, and more plausible and in addition represents each speaker more equally, so we will present the four-factor solution below.

(6-5) Mode C (Speaker) loadings for the four-factor solution of Ndut and !Xóõ covariance matrices

	Factor 1	Factor 2	Factor 3	Factor 4
Ndut	1.059	0.1208E-01	2.182	0.2224
!Xóõ Speaker 1	1.121	0.5099	0.2943	2.527
!Xóõ Speaker 2	0.8205	2.478	0.5233	0.2503

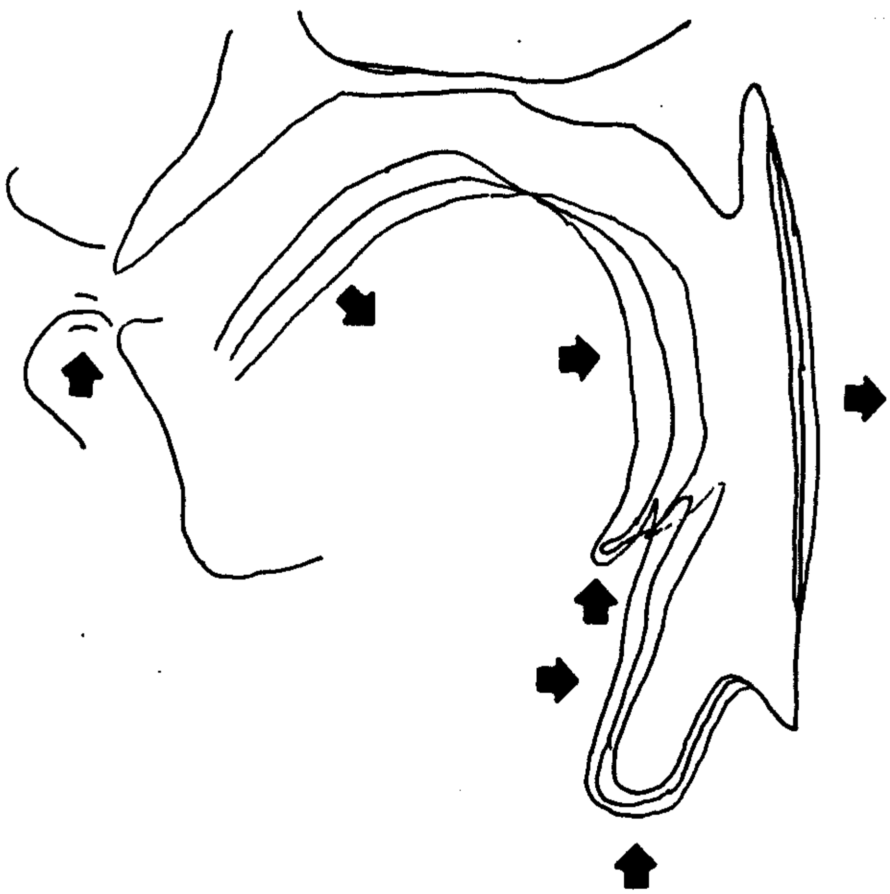
6.4 Discussion of the Ndut/!Xóõ four-factor solution

The articulatory displacements generated by the four-factor solution can be seen in figures (6-6)-(6-9). The first factor (6-6), more or less equally shared by all three speakers, resembles the English Front Raising Factor in Harshman et al. (1977). (Jackson 1988a:159 found that "the most reliably replicated axis of the phonetic vowel space generates tongue shapes similar to the Front Raising Factor of Harshman et al. (1977) and puts /i/- and /o/-like vowels at opposite extremes of the vowel space.") The cross-over point lies roughly under the beginning of the soft palate. As the tongue blade and front dorsum lower, the rear dorsum and root are pushed into the pharynx; as the front of the tongue is raised, the rear of the tongue is moved forward, widening the pharynx. In the Ndut/!Xóõ factor, retraction of the tongue root is accompanied by raising of the larynx, constriction of the pharyngeal wall below the epiglottis, and retraction of the pharyngeal wall (widening the pharyngeal cavity) at the level of the epiglottis and above.

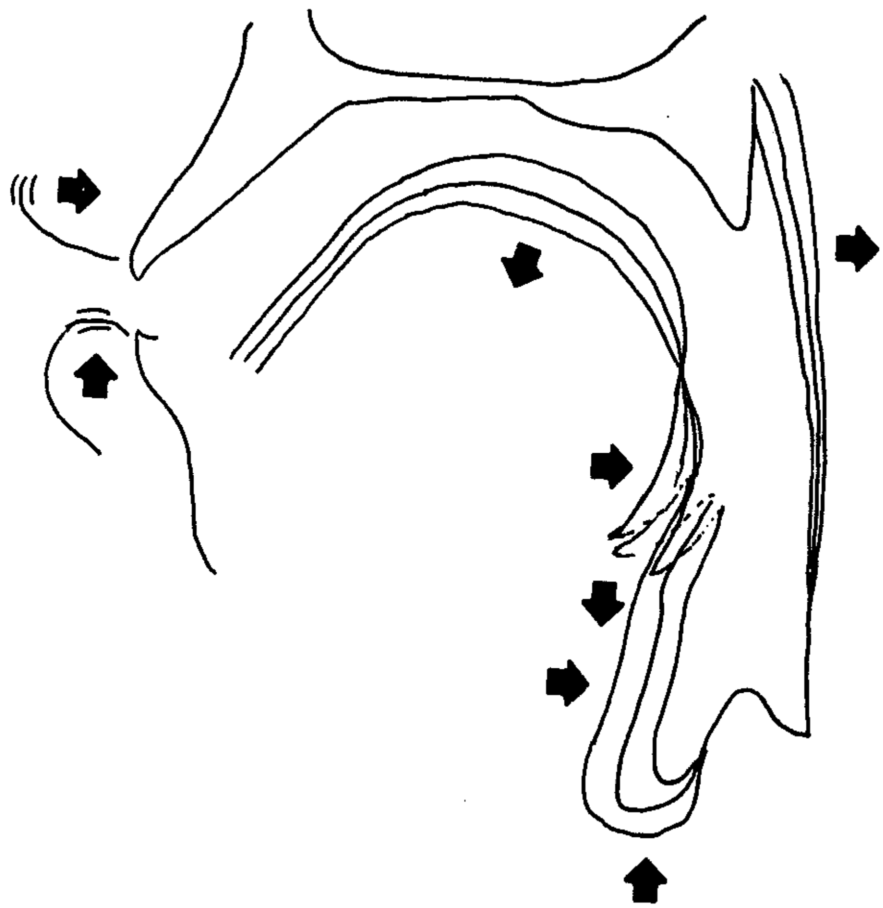
The cross-over point in the second Ndut/!Xóõ factor (6-7) has shifted to the middle pharynx above the tip of the epiglottis. As the tongue blade and dorsum are lowered, the tongue root is retracted quite far into the lower pharynx. Retraction of the tongue root occurs along the length of the epiglottis down to the larynx. Retraction of the tongue root is also accompanied by a large degree of larynx raising. There is little movement of the pharyngeal wall except near the velum. This factor is used by the !Xóõ speakers, and speaker 1 in particular.

The greatest movement in the third factor (6-8) takes place in the pharyngeal wall and the larynx which coordinates with movement of the tongue root to create an expanded or contracted pharynx. This factor is used primarily by the Ndut speaker. Movement of the tongue root is quite small, to a much smaller degree than was found with Akan, while the movement in the dorsal pharyngeal wall is substantial. There is also some balancing of movement between the front and rear dorsum of the tongue; the crossover point is further forward than in the first factor and lies under the center of the hard palate.

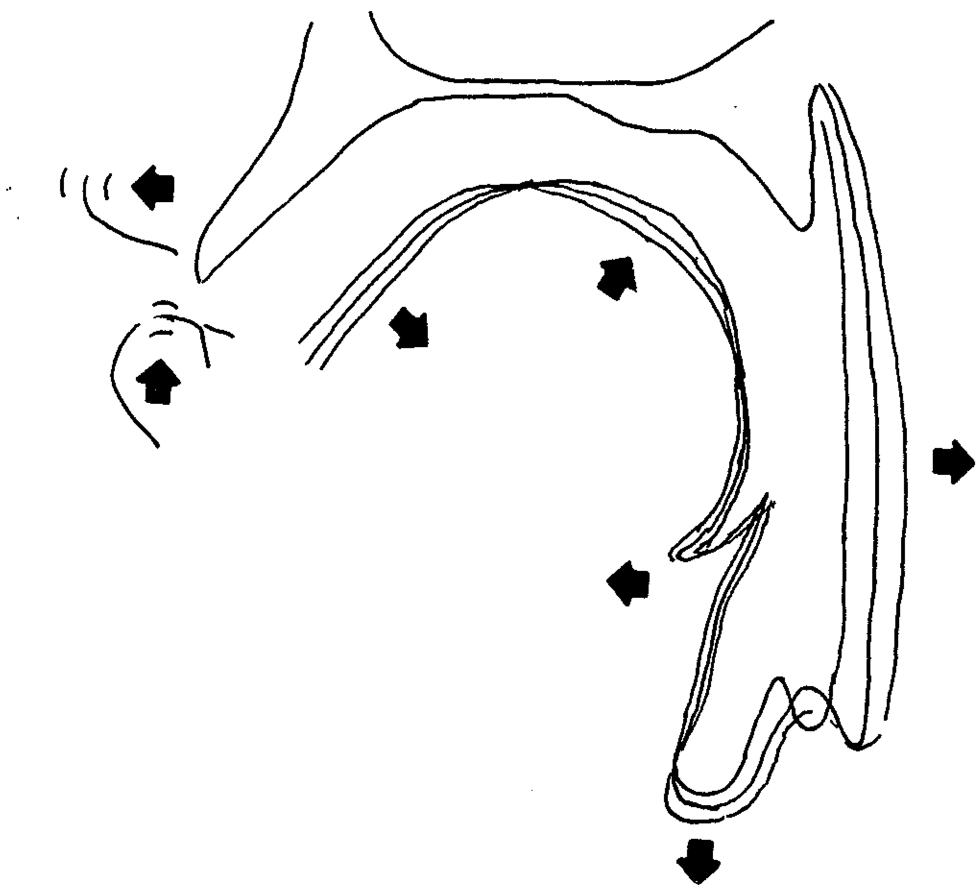
The fourth factor (6-9) is mainly utilized by the second !Xóõ speaker. It describes a slightly different set of pharyngeal movements. As the lower pharynx is constricted by the pharyngeal wall and raising of the larynx, the tongue root is actually slightly advanced. At the same time, the pharyngeal cavity near the velum is expanded. In addition, the center of the tongue dorsum is raised.



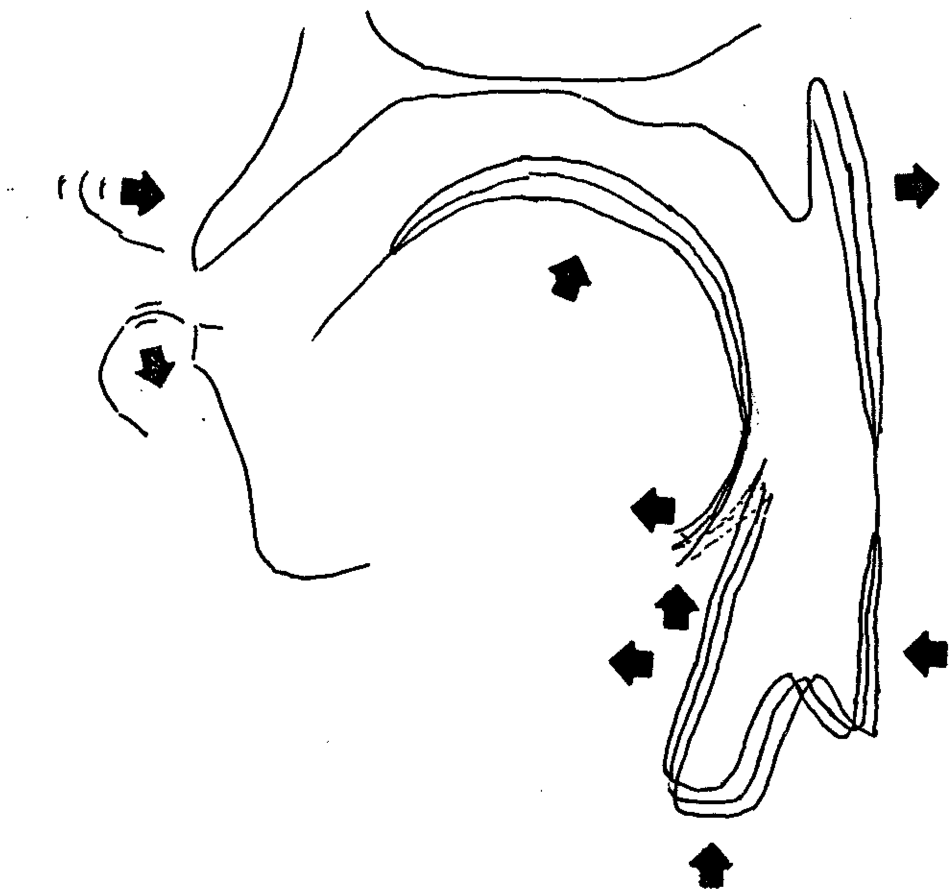
(6-6) Ndut and !Xóõ vowel Factor 1, from analysis of covariance matrices



(6-7) Ndut and !Xóõ vowel Factor 2, from analysis of covariance matrices



(6-8) Ndut and !Xóõ vowel Factor 3, from analysis of covariance matrices



(6-9) Ndut and !Xóõ vowel Factor 4, from analysis of covariance matrices

The results of this analysis are somewhat fragmented. Even in analyses of speakers of the same language (the more normal use of PARAFAC), there are variations, sometimes substantial, in the degree to which the behavior of different speakers is described by the various factors, and in fact, this is the system variation hypothesis that is a necessary assumption of PARAFAC. With only three speakers from two different languages it is more difficult to determine which movements characterize a language and which describe individual variation. The summary below must be taken with that in mind.

Since all three speakers load fairly equally on Factor 1 and as Factor 1 accounts for the largest proportion of variance, we can assume that this factor describes a basic set of vowel movements. However, it should be noted that a fair amount of tongue root retraction and some larynx raising is included. Factor 2 accounts for tongue root retraction and larynx raising in !Xóõ. It displays the greatest amount of constriction in the laryngopharynx of any factor seen so far, far more than in Akan or Arabic. We can conclude that Factor 2 is mainly responsible for the production of strident vowels in !Xóõ, but as there are no segment loadings in an analysis of covariance matrices, we do not know the degree to which the pharyngealized vowels of !Xóõ would also load on this factor. Factor 3 describes pharyngeal wall and larynx movements for the Ndut speaker. Very little retraction of the tongue root is included, perhaps because Factor 1 contains tongue root retraction. Since the fourth factor mainly affects only one speaker of !Xóõ and not the other two speakers in this analysis and accounts for the least amount of variance, it is interpreted as largely accounting for a personal pattern of behavior, resulting in somewhat less laryngopharyngeal constriction than the other !Xóõ speaker. Although the third factor is also only salient for one of the speakers, the essential nature of this movement pattern for describing the phonological contrasts of the language suggest it is less likely to be individual.

6.5 Summary of the chapter

This chapter has presented the results of PARAFAC analyses of language data from two unrelated languages, Ndut and !Xóõ, using covariance matrices. The first factor, shared fairly equally among the three speakers and thus most likely represents vowel gestures used in both languages, displays a fair amount of tongue root and larynx movement. An even greater degree of laryngopharyngeal constriction caused by tongue root retraction and larynx raising is seen in the second factor, which exclusively describes a pattern of movement in !Xóõ. The third factor, which describes movement by the Ndut speaker, shows large movements of the pharyngeal wall and larynx, along with small movements of the tongue root, to expand or constrict the pharynx. Taken together, Factors 1 and 3 would provide for a pattern of movement rather similar to Akan Factor 2, which described movements for forming [±ATR] vowels. In the next chapter, we will be able to compare patterns of movements among all four languages in this study more directly.

CHAPTER 7 CROSS-LANGUAGE COMPARISONS: Analysis of pooled data from all languages using covariance matrices

7.0 Introduction

So far we have constructed models of movement for individual languages or pairs of languages. These individual analyses can be compared to each other by visual inspection and their similarities and differences described, but it will be more useful to have a way to quantitatively say just how similar or different they are. Another way of comparing pharyngeal articulations in these languages is to analyze the pooled data to find out whether the different languages are modeled by the same factors or different ones. This is somewhat similar to the way in which Jackson (1988) constructed a model of articulatory primes in his work on vowels. In our case, we will not be able to claim that the factors we recover actually represent articulatory primes - for that we would need a much larger sample of data than is available. But a pooled analysis will allow us to make more direct comparisons between the languages used in this study.

7.1 PARAFAC analysis of pooled data using covariance matrices: data and selection of optimum number of dimensionalities

Covariance matrices were computed for eleven speakers: all four Akan speakers, both !Xóõ speakers, the Ndut speaker, and four Arabic speakers. In the case of the Arabic speakers, segments with too many missing data points were dropped from the computations. The segments selected for the four Arabic speakers are listed in (7-1), along with the segment inventories for the other speakers. PARAFAC analysis then proceeded as before. A summary of the results is shown in (7-2).

(7-1) Speakers and segments selected for cross-language analysis

Arabic:

Ghazali (Appendix A, IIa)	s sˤ t tˤ k q ħ ʕ i iˤ æ ɑ u uˤ
Metoui (1989)	i iˤ æ ɑ u uˤ
Bukshaisha (1985)	s sˤ ħ ʕ
Ali (Appendix A, IIb)	s sˤ t tˤ k q i iˤ æ ɑ u
All four Akan speakers	i ɪ e ɛ ɑ ɔ o ʊ u
Ndut (Gueye)	i ɪ e ɛ ə a ɔ ʊ u iː ɪː eː ɛː əː aː ɔː ʊː uː
!Xóõ Speaker 1 (Appendix B)	i e ɑ o u aˤ o̧ˤ uˤ ɑ̰ ṵ
!Xóõ Speaker 2 (Appendix B)	i e ɑ o o̧ u aˤ oˤ uˤ ɑ̰ ṵ

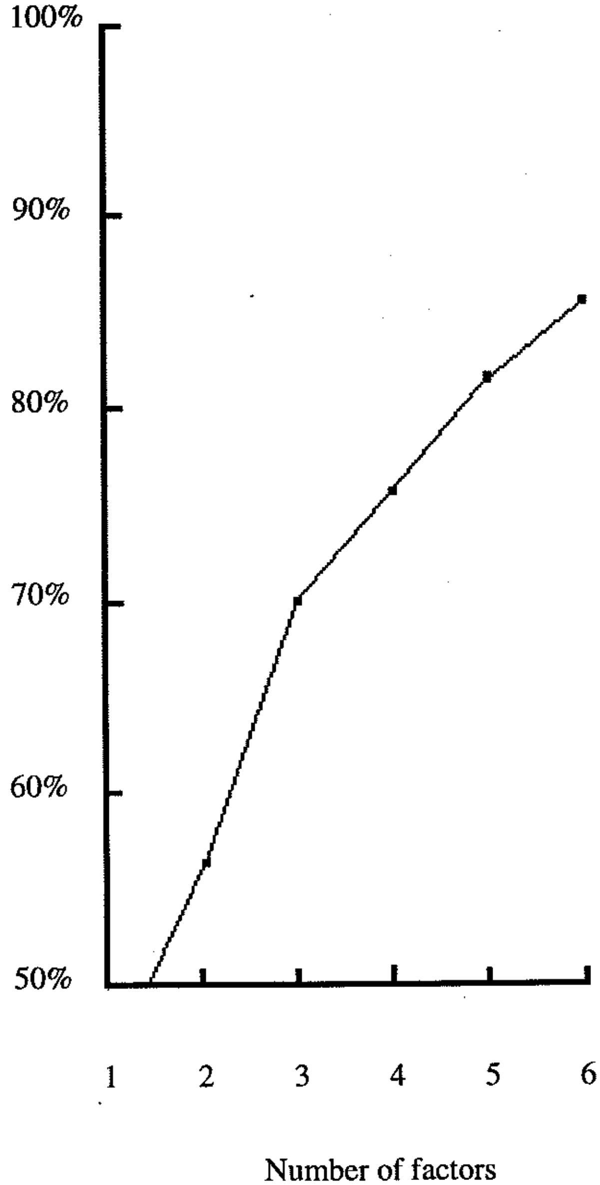
(7-2) Summary of PARAFAC analyses for cross-language data (eleven speakers)

Number of factors	Converged (iterations in parentheses)	Unique	R^2	System variation	Correlation between factors
1	yes (70, 69, 12)	yes	.31	yes	n.a.
2	yes (16, 14, 16)	yes	.57	yes	
3	yes (20, 19, 13)	yes	.70	yes	low
4	yes (23, 21, 24)	yes	.76	yes	mid
5	yes (26, 27, 29, 35, 30, 29, 23)	6/7	.82	yes	mid
6	yes (25, 31, 27)	2/3	.86	yes	mid

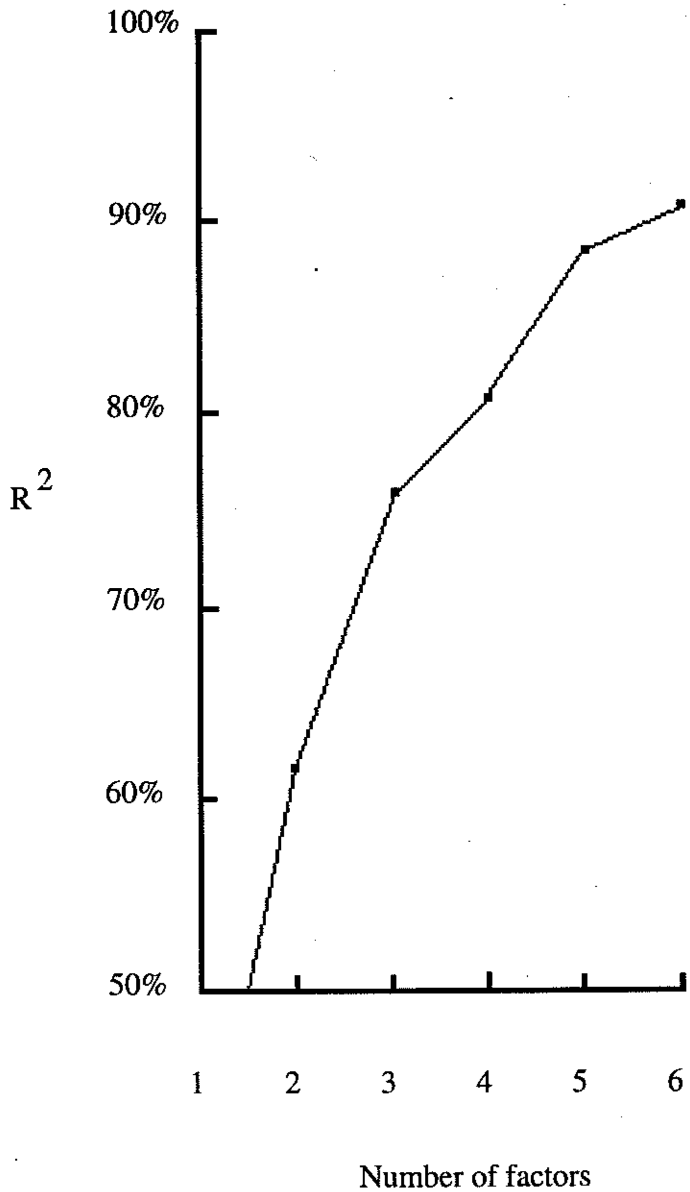
A plot of the R^2 values is shown in (7-3). The sharpest bend is at three factors with a smaller bend at five factors. Three factors seems overly simplistic for the range of data encountered here, and in fact several of the Arabic speakers do not load highly on any of the three factors - this solution does not fit their behavior well. The four-factor solution and the first four factors of the five-factor solution are very similar, but the fifth factor has the advantage of fitting two of the Arabic speakers well. The increase in R^2 drops off between five and six factors, suggesting that five factors is the optimum for this data set.

Additional corroboration for selecting the five-factor solution comes from comparing the results of analyzing half of the data set with the analyses of the entire data set. The speakers were divided into two groups. Split-half A contained five speakers: Akan Speakers 1 and 2, Ghazali, Metoui, and Xóõ Speaker 1. Split-half B contained the remaining six speakers: Akan Speakers 3 and 4, Bukshaisha, Ali, Ndut, Xóõ Speaker 2. Plots of the R^2 for each half are given in (7-4) and (7-5). The sharpest bent for Split-half B (7-5) occurs at four factors. However, Split-half A (7-4) has difficulties in reducing the data to four factors, leaving us with a choice between three and five factors.

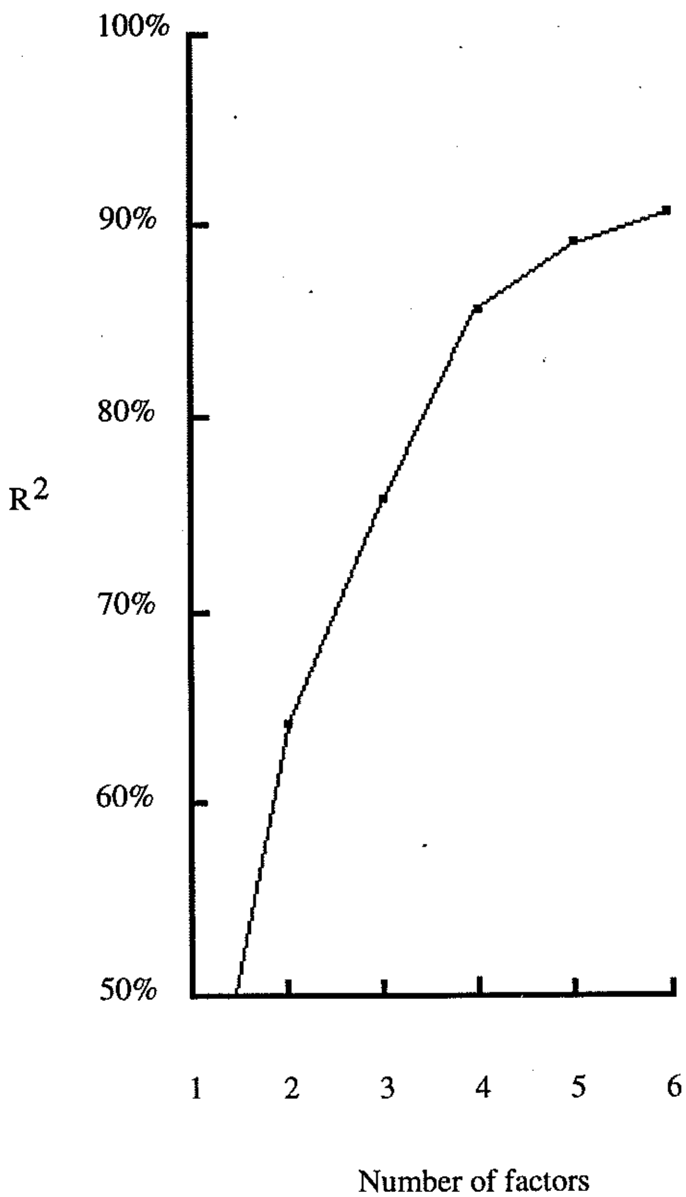
Split-half B is more similar to the overall solution (11 speakers). Split-half A, which has fewer speakers, may not contain an adequate sample of segments to be representative of the whole. The articulatory factor loadings from split-half B were held fixed while fitting data of 11 speakers and the reverse was also done, whereby the articulatory factor loadings from the overall solution were fit to the data in split-half B. The fits for these two sets of analyses are given in (7-6a-b) and the correlations between the articulatory factors derived from the entire data set solution and from Split-half B data set at four and five factors are given in (7-7a-b).



(7-3) Percentage of variance (R^2) accounted for by *n* factors for pooled data of eleven speakers. R^2 of 1-factor solution is 31%.



(7-4) Percentage of variance (R^2) accounted for by *n* factors for Split-half A of five speakers. R^2 of 1-factor solution is 37%.



(7-5) Percentage of variance (R^2) accounted for by *n* factors for Split-Half B of six speakers. R^2 of 1-factor solution is 37%.

(7-6a) PARAFAC fits using articulatory loadings from split-half B to data of all speakers (overall solution):

4 factors	R^2=.71
5 factors	R^2=.76

(7-6b) PARAFAC fits using articulatory loadings from the overall solution to split-half B:

4 factors	R^2=.80
5 factors	R^2=.86

(7-7a) Correlations of factors derived from split-half B and overall data sets at four factors:

split-half B	overall	correlation
Factor 1	Factor 1	.973
Factor 2	Factor 2	.989
Factor 3	Factor 3	.649
Factor 4	Factor 4	.975

(7-7b) Correlations of factors derived from split-half B and overall data sets at five factors:

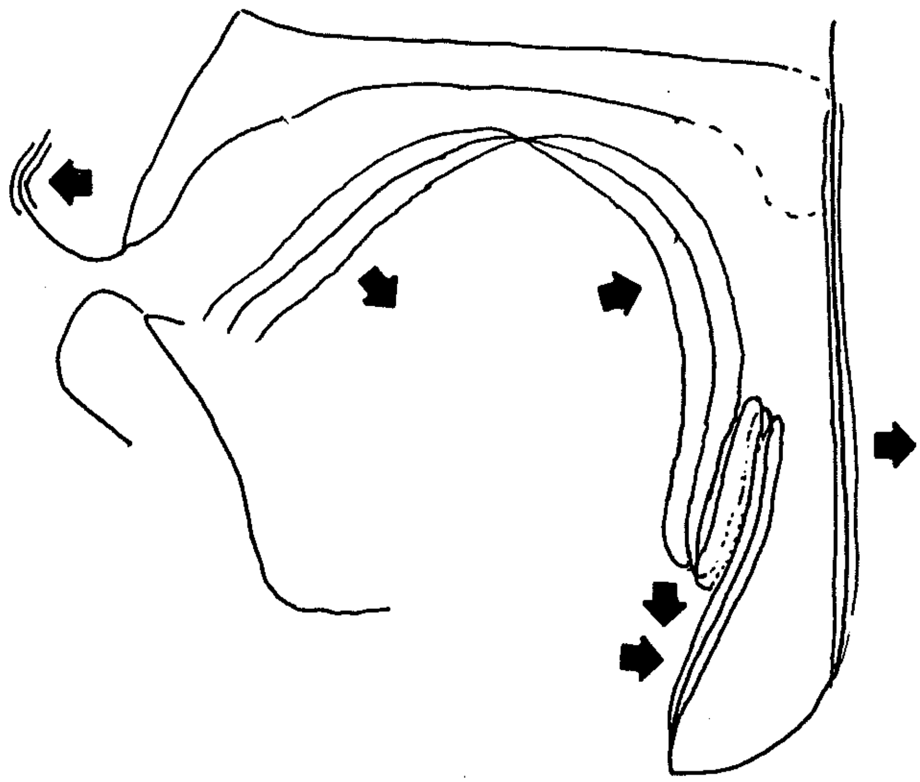
split-half B	overall	correlation
Factor 1	Factor 1	.990
Factor 2	Factor 2	.996
Factor 3	Factor 3	.978
Factor 5	Factor 4	.972
Factor 4	Factor 5	.822

As can be seen from (7-6b), the fit of the articulatory loadings derived from the overall data set to the Split-half B data set are much higher than the reverse (7-6a), and are thus better representative of the whole. The correlations between the articulatory loadings derived from the two data sets are higher with five factors (7-7b) (e.g. .996 and .990), while the lowest correlation is .822 in (7-7b) but .649 in (7-7a), which suggests that five factors fit the data better than four.

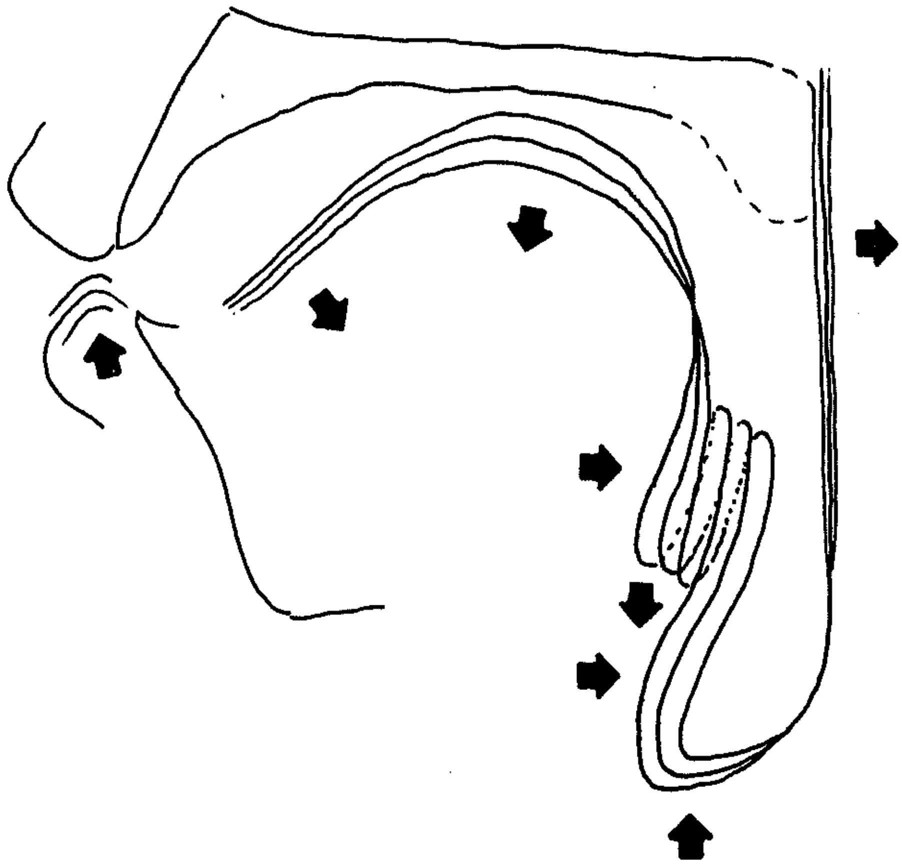
7.2 Discussion of the five-factor solution for the eleven-speaker data set

The articulatory movements generated by the five-factor solution are illustrated in (7-8)-(7-12). The first factor (7-8) balances movement of the blade and front dorsum with movement of the rear dorsum and of the tongue root above the pocket of the epiglottis. The cross-over point is under the hard palate, further forward than the English Front-Raising Factor, and describes a front-vowel gesture at one extreme (possibly [e] rather than [i]) and an [u]-like gesture at the other extreme. There is slight movement of the tongue root below the pocket of the epiglottis as well as some movement of the pharyngeal wall. The speakers with the largest loadings on this factor are the four Akan speakers, especially speakers 2 and 4, the Ndut speaker, and Ghazali (7-13). Given that the segment inventories for these speakers are all vowels, with the exception of Ghazali whose inventory is half vowels and half consonants, this factor must show the mean set of movements required to form the vowels in this data set.

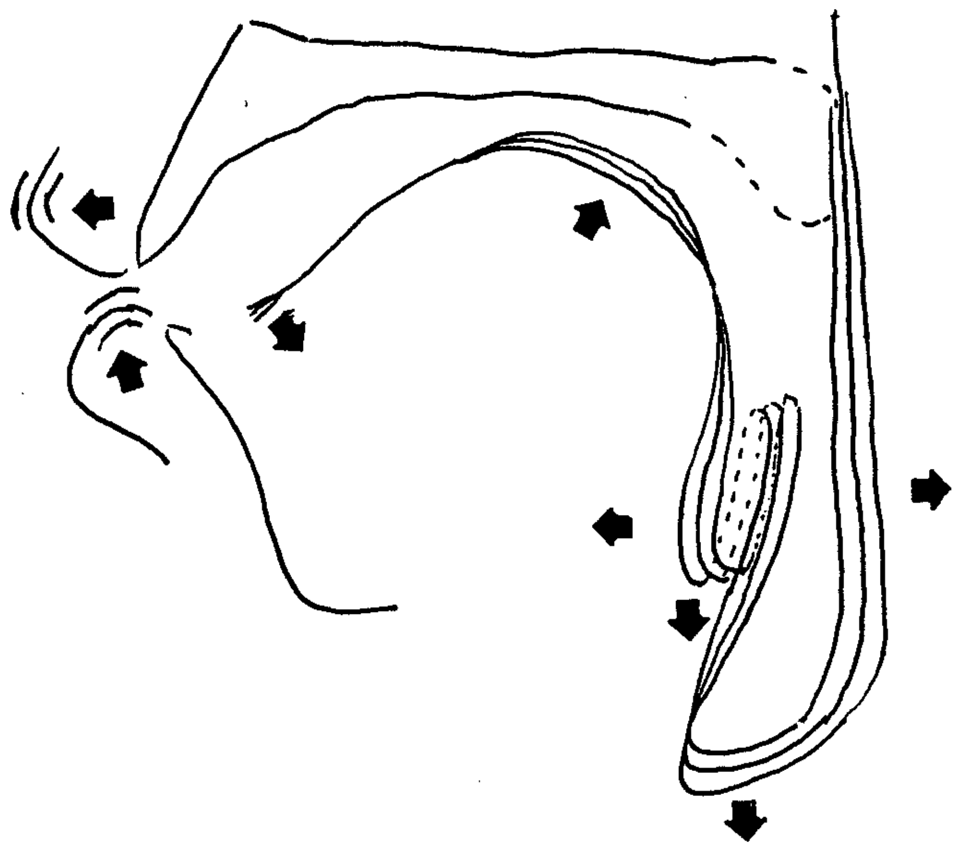
The second factor (7-9) describes large movements of the tongue root beginning just above the tip of the epiglottis and continuing all the way down to the larynx. Retraction of the tongue root is accompanied by raising of the larynx. These movements are balanced by lowering of the rear dorsum as the tongue root is retracted. Conversely, as the rear dorsum is raised to form an [u]-like gesture, the tongue root is advanced and the



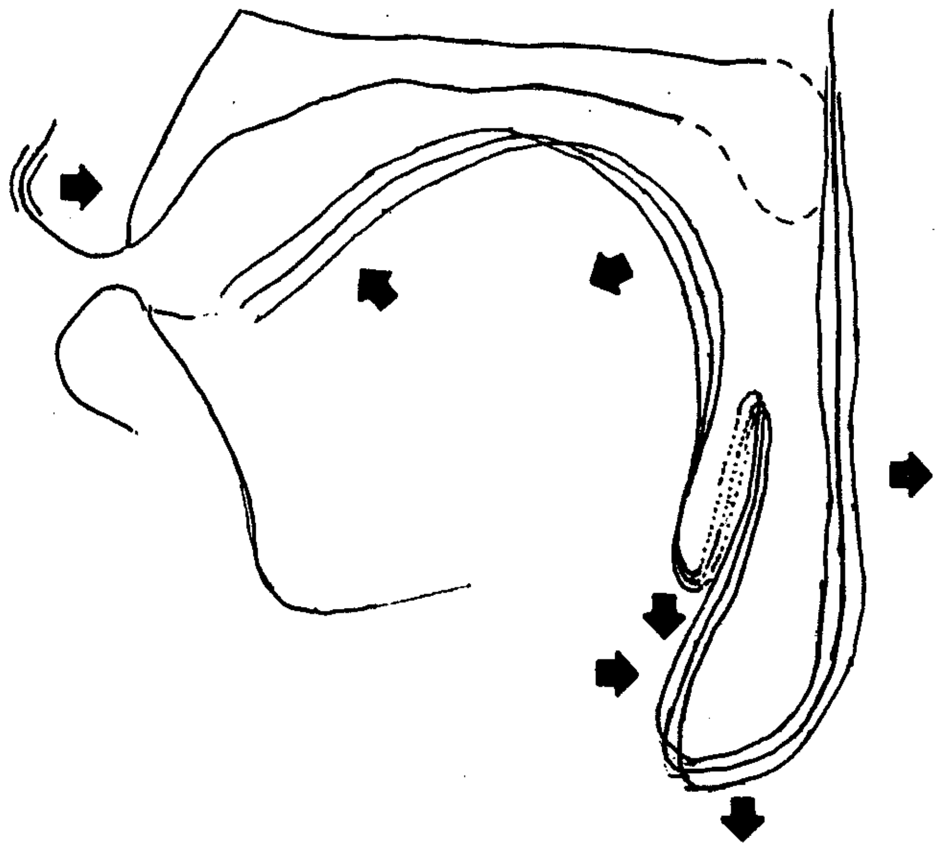
(7-8) Factor 1 of pooled data set of 11 speakers.



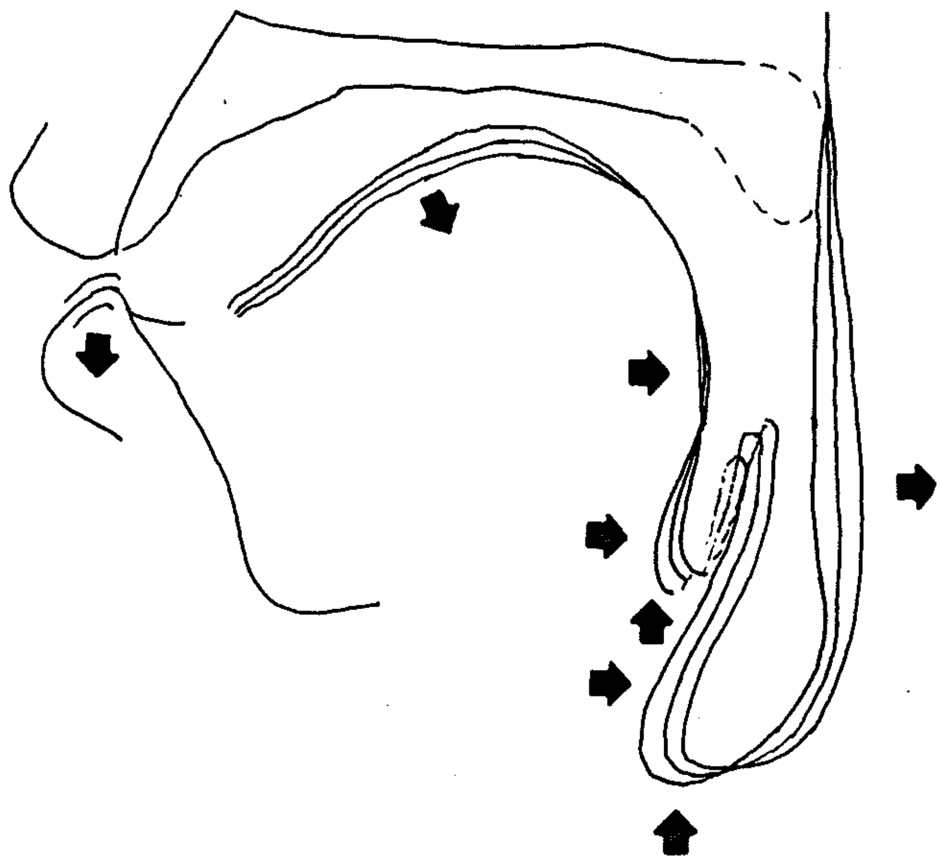
(7-9) Factor 2 of pooled data set of 11 speakers.



(7-10) Factor 3 of pooled data set of 11 speakers.



(7-11) Factor 4 of pooled data set of 11 speakers.



(7-12) Factor 5 of pooled data set of 11 speakers.

larynx lowered. This factor mainly contributes to articulatory movements of the two !Xóõ speakers (7-13), who exhibit the most extreme lower pharyngeal constrictions. It is quite similar to Ndut/!Xóõ Factor 2 (6-7).

Factor 3 (7-10) is primarily concerned with movement in the pharynx. Unlike Factor 2, it shows almost no movement of the tongue above the tip of the epiglottis. As the root of the tongue advances (with the greatest amount of movement at the pocket of the epiglottis), the larynx is lowered and the pharyngeal wall moves back, creating an expanded pharynx. The four Akan speakers and the Ǹdut speaker load highly on this factor, as does Metoui, surprisingly (7-13). The fourth Akan speaker and the Ndut speaker load the highest. From the type of movements described by this factor, the speakers which use it, and its similarity to the second Akan factor which separates [±ATR] vowels, we can infer that this factor represents the difference between vowel harmony sets in Akan and Ndut.

The fourth factor (7-11) is fairly similar to the first: the crossover point is at the same place under the hard palate and the magnitude of movement of the front of the tongue is similar. However, Factor 4 shows less movement of the rear dorsum of the tongue and more of the tongue root below the pocket of the epiglottis. In addition, there is substantial movement of the larynx and of the pharyngeal wall. As the tongue root retracts, the larynx is lowered and the pharyngeal wall moves back. This factor appears to be a Front-Raising factor with adjustments in the pharynx and perhaps reflects individual strategies for vowel production. The speakers which load on this factor in decreasing order, starting with the highest, are Akan 1, Akan 3, Akan 2 and Metoui (7-13).

The last factor, Factor 5 (7-12), exhibits a different organization of movements in the pharynx. As the tongue root moves back, the larynx is raised, but the pharynx wall moves back. Thus, the volume of the pharynx is not changed as greatly as with Factor 3, where the structures worked together to expand or constrict the pharynx. The Qatari speaker, whose inventory only includes consonants, loads highest on this factor, followed by Ghazali, one !Xóõ speaker, and the Ndut speaker. The extent to which each speaker loads on each factor is given in (7-13):

(7-13) Mode C (Speaker) loadings for the five factors (rounded off; see Appendix C)

Speaker	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Akan 1	1.1	0.66	1.8	5	0.37
Akan 2	2.5	0.33	0.56	0.99	0
Akan 3	0.95	0	1.3	2	0
Akan 4	3.1	0.28	2.5	0.15	0.25
Ndut	1	0.28	2.4	0.38	1.1
!Xóõ 1 (B)	0.6	5.5	0.45	0.21	0.18
!Xóõ 2 (G)	0.76	2.7	0.22	0.11	1.1
Ghazali	0.87	0.51	0.32	0.36	2.7
Metoui	0	0.13	1.3	0.76	0.25
Qatari	-0.26	0	0.16	0.55	4.7
Ali	0.34	0.75	0	0.51	0.44

7.3 Correlations between blocks of loadings and partitioning of the data set

We noted above that there are some similarities between different factors. For instance, the tongue patterns of Factors 1 and 4 are similar, but movement of the larynx and pharyngeal wall differ. This begs the question: are there underlying similarities of movements between different components of the vocal tract which are obscured when bundled together? By separating tongue loadings from larynx and pharyngeal wall loadings we might find fewer distinct patterns of movement which in combination yield different factors. To test this, the articulatory loadings for each factor were partitioned into two sets: the first containing seventeen tongue loadings, including all of the tongue root, and the second containing eleven loadings of larynx and epiglottis height and pharyngeal wall movement. Correlations within these two sets are given in (7-14) and (7-15). Loadings for lips were not included in either set. (When included with either set, they caused many of the correlations between factors to become zero.) By way of comparison, correlations for the loadings as a whole are given in (7-16).

(7-14) Correlation matrix for 17 tongue loadings

	1	2	3	4	5
1	1.000				
2	0.289	1.000			
3	-9.185E-3	-0.696	1.000		
4	-0.889	0.076	-0.281	1.000	
5	0.457	0.819	-0.592	-0.116	1.000

(7-15) Correlation matrix for 11 pharyngeal wall, epiglottis and larynx height loadings

	1	2	3	4	5
1	1.000				
2	0.816	1.000			
3	-0.333	-0.626	1.000		
4	0.661	0.431	0.217	1.000	
5	0.684	0.560	0.128	0.841	1.000

(7-16) Correlation matrix for 30 loadings

	1	2	3	4	5
1	1.000				
2	0.311	1.000			
3	-0.019	-0.427	1.000		
4	-0.755	0.109	0.156	1.000	
5	0.398	0.692	-0.033	0.160	1.000

Looking at (7-16), we find that there are strong similarities between Factors 1 and 4 and Factors 2 and 5. When we look at the partitioned correlation matrices, we find that the tongue loadings are most similar in Factors 1 and 4 and in Factors 2 and 5 (7-14), and the pharyngeal and laryngeal loadings are most similar in Factors 1 and 2 and in Factors 4 and 5 (7-15). It would appear that several of the partitioned factors could be eliminated. Rather than make an *a priori* decision, we will fit the ten partitioned factors (five tongue and five pharyngeal) against the Akan, Arabic, Ndut and !Xóõ data. Factors which have little effect on the fit will be dropped, until we reach a set of factors which best models each data set with little loss of fit (not greater than 1-2% per factor).

7.4 Backward-stepping analyses

In the partitioned set of loadings, the first five factors contain the tongue loadings (for grid points e1-t16) (see (3-4)). Loadings for larynx and pharynx positions are set to zero. These factors will be referred to as T1-T5. Factors 6-10 are the loadings of pharynx and larynx position (p1-8, lpx, epi, lx), with tongue positions set to zero. These factors will be referred to as P1-P5. All loadings are held fixed during subsequent calculations of fit. When the partitioned loadings were used against real, unnormalized data, they were automatically rescaled by PARAFAC. In the process, the signs of the loadings have been reversed for some factors to better fit the data. This is the case for factors P2 and T3. In the case of P2, movement of the pharyngeal wall is given a negative rather than a positive sign and movement of the larynx a positive rather than a negative sign. The result is when a solution shows a positive loading for factor P2, it is indicating advancement or constriction of the pharyngeal wall accompanied by lowering of the larynx. The same thing has happened in the case of factor T3, so that for a positive loading on this factor, the root of the tongue from the larynx to the tip of epiglottis is retracted, the rear dorsum of the tongue is lowered and the tip is raised slightly. Both the original set of loadings and the rescaled, partitioned set are given in Appendix C.

Initially, all ten factors will be fit to each data set: Akan vowels, Arabic vowels, Arabic consonants, and Ndut and !Xóõ vowels. Factors which are highly correlated with other factors or which carry a very low load (contribute least to R^2) will be dropped until we reach an optimum set of factors for each data set. In general, we will only drop factors which affect R^2 by less than 2% (although we will try to stay closer to 1%). An exception will be made if two factors are highly correlated: the factor carrying the least load will be dropped regardless of the effect on R^2. In all cases three solutions or trials will be run at each level from different starting points (random numbers generated by the PARAFAC program).

7.4.1 Akan

In Akan, all five tongue factors carry heavier loads than any of the pharynx factors. The correlations between factors are given in (7-17) and the root mean squared contribution for each factor in (7-18).

(7-17) Correlations of factor loadings for Akan

	T1	T3	T2	T4	T5	P4	P2	P1	P5	P3
T1	1.000									
T3	0.069	1.000								
T2	0.289	0.845	1.000							
T4	-0.847	0.270	0.072	1.000						
T5	0.494	0.605	0.908	-0.106	1.000					
P4	-0.108	-0.182	-0.018	-0.167	-0.062	1.000				
P2	0.003	0.005	0.000	0.004	0.002	-0.215	1.000			
P1	-0.080	-0.135	-0.013	-0.123	-0.-46	0.813	-0.628	1.000		
P5	-0.058	-0.098	-0.010	-0.089	-0.033	0.761	-0.503	0.767	1.000	
P3	-0.112	-0.189	-0.018	-0.173	-0.064	0.863	0.214	0.517	0.485	1.000

(7-18) Root mean squared contribution for each factor

T1	T3	T2	T4	T5	P4	P2	P1	P5	P3
3.667	3.227	2.946	2.535	1.747	1.474	1.270	1.267	1.052	0.8346

The highest correlations are for tongue factors T2 and T5 (.908) and for pharynx factors P4 and P3 (.863; the cross-product[1] is .907). Of these, factors T5 and P3 bear the least load and will be dropped first. Then we will drop the factors with low loads: P5 and P1. Factor P1 is also fairly highly correlated with factor P4 (0.813). Tongue factors T2 and T3 are also highly correlated (0.846) and we will experiment with dropping those. (7-19) shows the results:

[1]Cross products "measure the dependence or similarity of pairs of factors within each mode, taking into account both the profile and elevation of the factor loadings" (Lundy & Harshman, 1985). Equation 3a, Appendix B in Lundy & Harshman (1985) gives the formula used.

(7-19) Backward-stepping analysis for Akan

Nfac	R^2	-Factor	Factors remaining
10	.8615		All: T1-5, P1-5
9	.8494	-T5	T1-4, P1-5
8	.8402	-P3	T1-4, P1-2, P4-5
7	.8327	-P5	T1-4, P1-2, P4
6*	.8242	-P1	T1-4, P2, P4
5	.8017	-T2	T1, T3-4, P2, P4
5	.7965	-T4	T1-3, P2, P4
5	.7839	-P2	T1-4, P4
5	.7839	-P4	T1-4, P2
4	.7689	-T2, T4	T1, T3, P2, P4
3	.7285	-P2	T1, T3, P4

*Order of remaining factors by root mean squared contribution:

T1=3.730 T3=2.791 T4=2.390 T2=1.774 P4=1.431 P2=1.426

Dropping factors T5, P3, P5 and P1 in turn affects the fit by less than 1% in all but one case, and that is still less than 2%. After we reach six remaining factors, each factor that is dropped decreases the fit by more than 2%. The six remaining factors contain four tongue factors (T1, T3, T4, and T2) and two pharynx factors (P4 and P2). However, factors T3 and T2 are strongly correlated at 0.846 and factors T1 and T4 equally but inversely so at -0.847. Eliminating factor T2 only causes a 2.25% change in R^2 and is most expendable; dropping T4 as well reduces the fit by an additional 3.28%.

7.4.2 Arabic vowels (3 speakers: Metoui, Ghazali, Ali)

Running all ten factors against the Arabic vowel data gives us a different ranking of factors. Of the pharynx factors, P5 is weighted fairly heavily, as we might have predicted from the speaker loadings for the cross-language factor 5 (see (7-13) above). The correlations between factors are given in (7-20) and the root mean squared contribution for each factor in (7-21).

(7-20) Correlations of factor loadings for Arabic vowels

	T2	T4	P4	T1	T3	T5	P5	P1	P2	P3
T2	1.000									
T4	0.072	1.000								
P4	-0.018	-0.167	1.000							
T1	0.289	-0.847	-0.108	1.000						
T3	0.846	0.269	-0.182	0.069	1.000					
T5	0.908	-0.106	-0.062	0.494	0.605	1.000				
P5	-0.010	-0.089	0.761	-0.058	-0.098	-0.033	1.000			
P1	-0.013	-0.123	0.813	-0.080	-0.135	-0.046	0.767	1.000		
P2	0.000	0.004	-0.215	0.003	0.005	0.002	-0.503	-0.628	1.000	
P3	-0.018	-0.173	0.863	-0.112	-0.189	-0.064	0.485	0.517	0.214	1.000

(7-21) Root mean squared contribution for each factor for Arabic vowels

T2	T4	P4	T1	T3	T5	P5	P1	P2	P3
2.288	1.734	1.584	1.336	1.308	1.257	0.8971	0.5204	0.4551	0.3654

Once again, tongue factor T5 has the highest correlation with another factor, and will be dropped first. Pharynx factor P3 bears the least load and has the next highest correlation and will be dropped next. Next we will try dropping factors with the next smallest loads: P2 and P1 (P1 is also fairly highly correlated with P4). After tongue factor T5, T3 bears the smallest load and is also highly correlated with T2. However, we will find that as factors are dropped, ranking of remaining factors shifts, and T3 becomes relatively more important than T2.

(7-22) Backward-stepping analysis for Arabic vowels

Nfac	R^2	-Factor	Factors remaining
10	.7653		All: T1-5, P1-5
9	.7473	-T5	T1-4, P1-5
8	.7435	-P3	T1-4, P1-2, P4-5
7	.7393	-P2	T1-4, P1, P4-5
6*	.7343	-P1	T1-4, P4, P5
5	.6960	-P5	T1-4, P4
5	.6828	-T1	T2-4, P4, P5
5	.6838	-T2	T1, T3-4, P4, P5
4	.6438	-T1, P5	T2-4, P4

*Order of remaining factors by root mean squared contribution:

T4=1.829 T3=1.583 P4=1.490 T2=1.380 T1=1.267 P5=1.094

After we reach six remaining factors, we find that dropping factors bearing the smallest loads results in decreasing R^2 by 4 or 5%. We are left with four tongue factors, T4, T3, T2, T1 and two pharynx factors, P4, P5. However, we still have strong correlations between factors T3 and T2 (0.846), T4 and T1 (-0.847) and P4 and P5 (0.761). Dropping T2 decreases R^2 by 5.15%, dropping T1 decreases the fit by 5.05%, and dropping P5 decreases it by 3.83%. The remaining factors would be T4, T3, and P4.

7.4.3 Arabic consonants (three speakers: Ghazali, Ali, Bukshaisha)

Running ten factors against the Arabic consonant data for three speakers, we find all three runs are different. The first run is most divergent while the second two are more similar. The main cause of this problem is /k/, which has the highest number of missing values to be estimated. The third solution has the highest R^2, and we will present correlations (7-23) and the root mean squared contribution for each factor (7-24) from that solution.

(7-23) Correlations of factor loadings for Arabic consonants (three speakers)

	T2	P1	T3	T1	P5	P4	T4	T5	P2	P3
T2	1.000									
P1	-0.013	1.000								
T3	0.846	-0.135	1.000							
T1	0.289	-0.080	0.069	1.000						
P5	-0.010	0.767	-0.098	-0.058	1.000					
P4	-0.018	0.813	-0.182	-0.108	0.761	1.000				
T4	0.072	-0.123	0.269	-0.847	-0.089	-0.167	1.000			
T5	0.908	-0.046	0.605	0.494	-0.033	-0.062	-0.106	1.000		
P2	0.000	-0.628	0.005	0.003	-0.503	-0.215	0.004	0.002	1.000	
P3	-0.018	0.517	-0.189	-0.112	0.486	0.863	-0.173	-0.064	0.214	1.000

(7-24) Root mean squared contribution for each factor

T2	P1	T3	T1	P5	P4	T4	T5	P2	P3
3.101	2.705	2.208	2.090	1.748	1.722	1.342	1.310	1.168	1.165

Once again, factor T5 shows a high correlation with another factor (0.908 with T2) and has the lowest root mean squared contribution of the tongue factors. Factor P3 has the lowest overall load and the next highest correlation (0.863 with P4). Factor P2 bears the next smallest load, and we will try dropping it. Tongue factors T4 and T1 are fairly highly inversely correlated (-0.847), and as T4 bears the smaller load, we will try eliminating it first.

(7-25) Backward-stepping analysis for Arabic consonants (3 speakers)

Nfac	R^2	-Factor	Factors remaining
10	.7422		All: T1-5, P1-5
9	.7160	-T5	T1-4, P1-5
8	.7071	-P3	T1-4, P1-2, P4-5
7	.6918	-P2	T1-4, P1, P4-5
6*	.6901	-P1	T1-4, P4-5
6	.6560	-T4	T1-3, P1, P4-5
6	.6262	-T1	T2-4, P1, P4-5
6	.6628	-P4	T1-4, P1, P5
5	.6553	-P1, T4	T1-3, P4-5
5	.6287	-P1, T3	T1-2, T4, P4-5

*Order of remaining factors by root mean squared contribution:

T2=2.205 P5=2.106 P4=1.769 T1=1.730 T3=1.615 T4=1.164 (sol 3)

Although eliminating factor T5 causes a 2.6% drop in R^2, we will drop it anyway because of its very high correlation (0.908 with T2). Factors P3 and P2 were dropped with very little effect on R^2 as anticipated. Going from seven factors to six, neither T4 nor T1 could be dropped without considerable degradation of fit. Dropping P1, however, causes little change in fit, and we are left with six factors: four tongue factors (T2, T1, T3, T4) and two pharynx factors (P5, P4). Factors T2 and T3 are correlated at 0.846, P5 and P4 at 0.761 and T1 and T4 at -0.847. Dropping T4 decreases the fit by 3.48%, T3 by 6.14% and dropping P4 would decrease the fit by at least 2.9% . Dropping these factors leaves us with T2, P5, T1.

7.4.4 Arabic consonants (five speakers: Ghazali, Ali, Al-Ani, Ferguson and Abramson (two Damascan speakers))

Adding two more speakers to our data set of Arabic consonants results in a somewhat different analysis, with all tongue factors initially bearing higher loads than any of the pharynx factors. At ten factors, the first solution did not converge at 600 iterations. The second and third solutions are very similar, with loadings differing at the .01 place, but the order of the last two factors is switched. Solution three has a slightly higher R^2, and we will present correlations (7-26) and the root mean squared contribution for each factor (7-27) from that solution.

(7-26) Correlations of factor loadings for Arabic consonants (five speakers)

	T2	T1	T3	T4	T5	P1	P2	P4	P3	P5
T2	1.000									
T1	0.289	1.000								
T3	0.846	0.069	1.000							
T4	0.072	-0.847	0.269	1.000						
T5	0.908	0.494	0.605	-0.106	1.000					
P1	-0.013	-0.080	-0.135	-0.123	-0.046	1.000				
P2	0.000	0.003	0.005	0.004	0.002	-0.628	1.000			
P4	-0.018	-0.108	-0.182	-0.167	-0.062	0.813	-0.215	1.000		
P3	-0.018	-0.112	-0.189	-0.173	-0.064	0.517	0.214	0.863	1.000	
P5	-0.010	-0.058	-0.098	-0.089	-0.033	0.767	-0.503	0.761	0.485	1.000

(7-27) Root mean squared contribution for each factor for Arabic consonants (five speakers)

T2	T1	T3	T4	T5	P1	P2	P4	P3	P5
4.358	2.806	2.551	2.056	1.858	1.636	1.511	1.212	1.190	1.079

We need to eliminate T5 on the basis of its high correlation (0.908 with T2) alone, although we will see in (28) that it decreases the fit by more than 3%. For once P3 does not have the smallest root mean squared contribution (although it does in the second solution), however it is highly correlated with P4 (0.863) and we will eliminate it on that basis. Next we will try dropping P5 (low load), P4 (next lowest load) and T4 (next lowest load among tongue factors).

(7-28) Backward-stepping analysis for Arabic consonants (five speakers: Tunisian, Syrian, Qatari, two Damascan)

Nfac	R^2	-Factor	Factors remaining
10	.7318		All: T1-5, P1-5
9	.69995	-T5	T1-4, P1-5
8	.7050	-P3	T1-4, P1-2, P4-5
7*	.7111	-P2	T1-4, P1, P4-5
7	.6697	-P5	T1-4, P1-2, P4
6	.6662	-P2, P4	T1-4, P1, P5
6	.6617	-P2, T4	T1-3, P1, P4-5
6	.6570	-P2, P5	T1-4, P1, P4
6	.6551	-P2, P1	T1-4, P4, P5

*Order of remaining factors by root mean squared contribution:

T1=3.496 T3=2.388 T2=2.325 P4=2.192 T4=1.740 P1=1.284 P5=0.9426

We dropped T5 first because of its high correlation with T2, even though R^2 drops by more than 3%. Dropping P3 (and later P2) actually improves the fit. Eliminating P5 instead of P2 after P3 degrades the fit too much so we will retain it after all. P4 bears a relatively higher load than P2 at this point, so we drop P2 instead and find that this improves the fit (starred solution). We are unable to eliminate any more factors on the basis of effect on R^2 after the first three and are left with seven: four tongue factors (T1, T3, T2, T4) and three pharynx factors (P4, P1, P5). P4 is correlated with both P1 (0.813) and P5 (0.761); T3 is correlated with T2 (0.846) and T1 is inversely correlated with T4 (-0.847). Dropping correlated factors would leave us with T1, T3, P4.

7.4.5 Ndut and !Xóõ vowels

Fitting the ten factors to the Ndut and !Xóõ vowels data posed more of a challenge, as the data in this case are composed of covariance matrices rather than raw measurements. First the data were fit against normalized covariance matrices (EAD normalization with speaker mode C providing the scale of the data). The resulting R^2 was quite low (0.595), and only three factors (T2, T1, P3) showed a positive value for the root mean squared contribution for each factor. The root mean squared contribution for all remaining factors was zero. Using unnormalized covariance matrices provides us with a little more information on the other factors, although the net result is of course the same: the data can be modelled with three factors. At ten factors, all three trials produce nearly identical solutions. The correlations (7-29), root mean squared contribution for each factor (7-30) and summary of the backward-stepping analysis (7-31) are given below:

(7-29) Correlations of factor loadings for Ndut and !Xóõ vowels (unnormalized covariance matrices)

	T2	T1	P3	T4	T5	T3	P2	P4	P1	P5
T2	1.000									
T1	0.289	1.000								
P3	0.000	0.000	1.000							
T4	0.076	-0.775	0.000	1.000						
T5	0.907	0.500	0.000	-0.081	1.000					
T3	0.823	0.106	0.000	0.315	0.605	1.000				
P2	0.000	0.000	0.165	0.000	0.000	0.000	1.000			
P4	0.000	0.000	0.907	0.000	0.000	0.000	-0.188	1.000		
P1	0.000	0.000	0.636	0.000	0.000	0.000	-0.569	0.853	1.000	
P5	0.000	0.000	0.570	0.000	0.000	0.000	-0.478	0.783	0.798	1.000

(7-30) Root mean square contribution for each factor for Ndut and !Xóõ vowels (unnormalized covariance matrices)

T2	T1	P3	T4	T5	T3	P2	P4	P1	P5
10.88	6.973	2.468	2.286	2.221	1.786	1.770	1.005	0.6303	0.4643

(7-31) Backward-stepping analysis of Ndut and !Xóõ (3 speakers): fits to unnormalized covariance matrices

Nfac	R^2	-Factor	Factors remaining
10	.6660		All: T1-5, P1-5
8	.6612	-T5, P4	T1-4, P1-3, P5
8	.6569	-T5, P3	T1-4, P1-2, P4-5
7	.6609	-P4, P5	T1-4, P1-3
7	.6534	-P1, P3	T1-4, P2, P4-5
7	.6567	-P3, P5	T1-4, P1-2, P4
6	.6589	-P4, P5, P1	T1-4, P2, P3
5	.6510	-T3	T1-2, T4, P2, P3
4	.6423	-P3	T1-2, T4, P2
4	.6398	-T4	T1-2, P2-3
3*	.6313	-P3, T4	T1-2, P2
3	.6292	-P2, T4	T1-2, P3
2	.4402	-P3, T1	T2, P3

*Order of remaining factors by root mean squared contribution:

T2=9.896 T1=6.961 P2=1.651

Looking at (7-29), factors T5, T3 and T2 are all highly correlated, so we will drop all but one of these. Factors P3 and P4 are also highly correlated and we will drop P4 first with its relatively lower load. P5 and P1 have the lowest root mean squared contributions and will be dropped next (see Nfac=6). T3, P3 and T4 can also be dropped without affecting R^2 much. At three factors, retaining P2 over P3 gives a higher R^2 (starred solution). We are left with T2, T1, and P2 (starred solution).

Correlations are negligible. !Xóõ speaker 1 loads evenly on all three factors but somewhat higher on T2, !Xóõ speaker 2 loads highest on P2, the Ndut speaker has the highest weights in general, and also loads highest on P2.

In (7-13) it was shown that both !Xóõ speakers loaded highest on Combined Factor 2 and that Combined Factor 2 was not ranked highly by any other data set. In the backward-stepping analysis above, both halves of Combined Factor 2, i.e. T2 and P2, are selected by the Ndut/!Xóõ data set. Combined Factor 2 (7-9) is very similar to Ndut/Factor 2 (6-7).

Combined Factor 1 was ranked next highest by both !Xóõ speakers (7-13), and has a reasonable weight by the Ndut speaker. This perhaps explains why T1 was selected in the backward-stepping analysis, although one Xóõ speaker and the Ndut speaker ranked other factors higher in the combined analysis. The second Xóõ speaker used more of Combined Factor 5 than Combined Factor 1. In §6.3, the second Xóõ speaker was individually modeled by Ndut/Xóõ Factor 4 (6-9); Ndut/Xóõ Factor 4 (6-9) and Combined Factor 5 (7-12) are quite similar.

In (7-13) Ndut loaded highest on Combined Factor 3 (7-10), and had similar weights on Combined Factor 5 (7-12) and Combined Factor 1 (7-8). Only its weighting on Combined Factor 1 is represented by the selection of T1 in the backward-stepping analysis.

7.4.6 Summary of backward-stepping analyses

(7-32) provides a list of factors which best fit each set of data. Factors which are correlated with other factors but whose removal degrades fit by more than 2% are listed in parentheses.

(7-32) Summary of factors for modeling each data set

Akan vowels:	T1	T3	P4	P2	(T4)	(T2)	
Arabic vowels:	T4	T3	P4	(T2)	(T1)	(P5)	
Arabic consonants (3 speakers):	T2	P5	T1	(P4)	(T3)	(T4)	
Arabic consonants (5 speakers):	T1	T3	P4	(T2)	(T4)	(P1)	(P5)
Ndut and!Xóõ vowels:	T2	T1	P2				

T1, T3 and P4 are found most frequently, but all of the partitioned factors except P1, T5 and P3 have at least one mention. From (7-32) we can see that Akan vowels and Arabic consonants (five-speaker solution) share the most number of factors, but this does not tell us how they are similar. In the next section, we will show the segment loadings from each language for each partitioned factor, which will give us a better understanding of what the partitioned factors are modelling.

7.5 Comparison of partitioned factors

The segment loadings, or mode B loadings in PARAFAC terms, are produced with each trial run of PARAFAC unless that mode is held fixed. In the backward-stepping analyses, above, we held the measurement mode (mode A in PARAFAC terms), i.e., the grid positions for tongue, pharynx and larynx position, fixed. (We are referring to the articulatory loadings in Mode A as factors.) The program then calculates how well these fixed factors fit the data and in the process calculates how much of factor X goes toward modelling segment Y for speaker Z. As we eliminated unnecessary factors in the backward-stepping analyses for each language, we were left with a set of factors which best models that language, given that these factors were imposed on the language. None of the fixed factors is identical to a factor in the original, unconstrained analysis, and thus will not fit that language as well as the original, but it does provide a common basis for comparing each language and the way in which the fixed factors model the data for each segment.

We have taken the segment loadings for each fixed, partitioned factor and plotted them on a common scale for comparison. In each case, we are using the solution which was starred in each of the tables summarizing the backward-stepping analyses for each language.[2] The segment loadings for the languages closest to the scale are the most important. Languages listed in parentheses reflect both a lower weight on that factor and a correlation to a higher-ranked factor, and are presented for comparison only. We cannot present segment loadings for Ndut/!Xóõ, as the fit was not to raw measurement data but to covariance matrices. Thus we will be looking at four data sets: Akan vowels, the three-speaker data set for Arabic consonants (referred to as Arabic (3) in all figures below), the five-speaker data set for Arabic consonants (Arabic (5)), and Arabic vowels.

Before we present the segment loadings, the movements produced by each factor are reviewed in (7-33). Each partitioned factor has been given a mnemonic name.

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[2]Segment loadings may vary a little as factors are removed. For example, in the backward-stepping analyses for Akan, the segment loadings for factor P4 were identical at 6 factors remaining and at 4 factors remaining, while the loadings for T1 varied a little, although the relative placement of the segments remained the same.

(7-33) Summary of movements for each partitioned factor (refer to figures (7-8)-(7-12))

T1=Upper Pharyngeal Constriction Factor

Balances movement of the blade and front dorsum with movement of the rear dorsum and of the tongue root above the pocket of the epiglottis; less movement below the pocket. Tongue root moves in the same direction as rear dorsum.

T2=Laryngopharyngeal Constriction Factor

Describes large movements of the tongue root beginning just above the tip of the epiglottis and continuing down to the larynx. Retraction of tongue root balanced by lowering of rear dorsum.

T3=Radical Constriction Factor

Describes large movements of the tongue root from the tip to the pocket of the epiglottis. As the tongue root retracts, the rear dorsum is lowered (to a lesser extent) and the tip of the tongue is slightly raised.

T4=Dorsal Constriction Factor

Similar to T1 with less movement of the rear dorsum and more of the tongue root below the pocket of the epiglottis. Tongue root retracts as rear dorsum lowers and front of tongue is raised.

P2=Larynx Raising Factor

Raising of the larynx is accompanied by some retraction of the pharyngeal wall (causing shortening and widening of the pharynx). Extent of movement of the pharyngeal wall is far less than that of the larynx, suggesting that larynx movement, independent of pharyngeal wall movement, is most important in this factor.

P4=Pharynx Expansion Factor

Lowering of the larynx is accompanied by substantial retraction of the pharyngeal wall (expanded pharynx).

P5=Pharynx Shifting Factor

Raising of the larynx is accompanied by substantial retraction of the pharyngeal wall. Thus the pharyngeal volume remains more or less constant but 'shifts in position'.

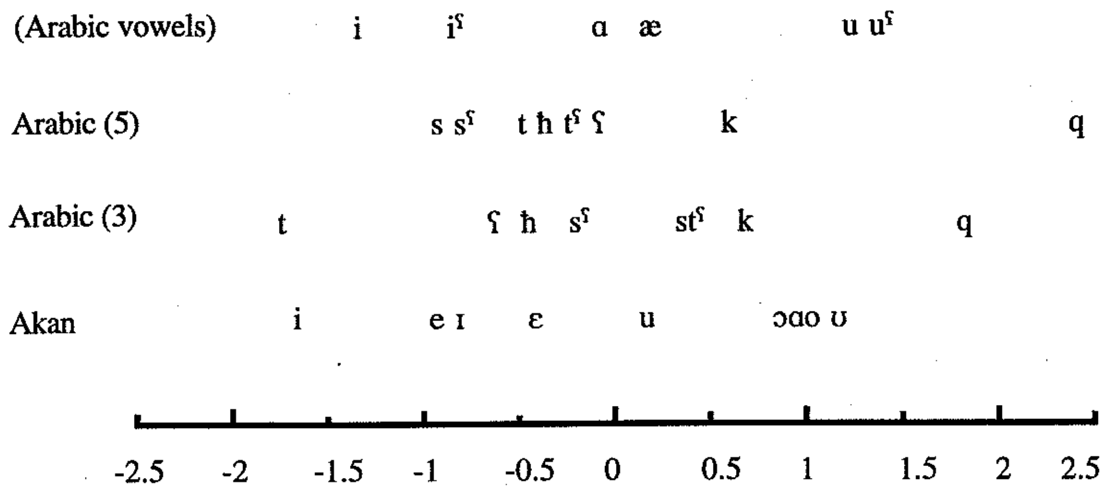
(P1) No movement of the larynx; some retraction of the pharyngeal wall.

(7-34) presents the segment loadings for the Upper Pharyngeal Constriction Factor (T1). Three data sets rank this factor highly. Arabic vowels do not, and are listed only for comparison. In Akan, the Upper Pharyngeal Constriction Factor separates front vowels from back vowels. It would almost do the same for Arabic, but [æ] and [ɑ] are switched. The back component of this factor models /q/ well in Arabic, but the front component is less interpretable. In the original cross-language solution (before partitioning), Ndut loaded heavily on combined-tongue-pharynx factor 1. In the backward-stepping analysis, both Ndut and !Xóõ speaker 1 load heavily on the Upper Pharyngeal Constriction Factor.

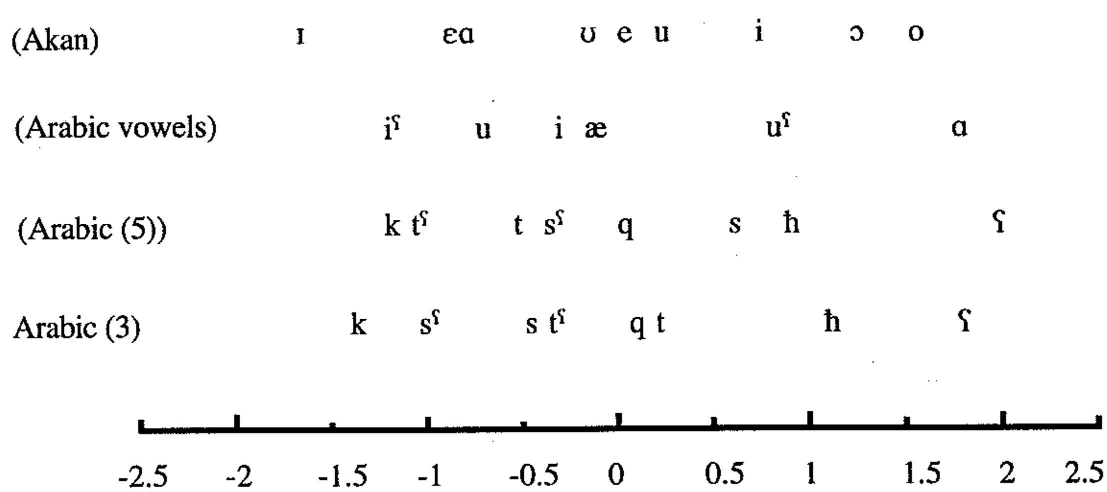
The segment loadings for the Laryngopharyngeal Constriction Factor (T2) are shown in (7-35). The only data sets which rank this factor highly are the three-speaker data set of Arabic consonants (Arabic (3)) and Ndut/!Xóõ (for which we have no segment data). This factor is correlated with the Radical Constriction Factor (T3) (0.846), and the other three data sets rank the Radical Constriction Factor more highly. In the original cross-language solution, the !Xóõ speakers weighed heavily on the combined tongue-pharynx factor 2, and !Xóõ speaker 1 loads heavily on the Laryngopharyngeal Constriction Factor (T2). In Arabic (3), it separates the pharyngeal from the non-pharyngeal consonants (and would do the same in Arabic (5)). In the Arabic vowel solution listed for comparison, [ɑ] loads as highly as /ʕ/.

Three data sets rank the Radical Constriction Factor (T3) highly, shown in (7-36). Ndut also loaded heavily on combined tongue-pharynx factor 3, but does not do so in the backward-stepping analysis. This is one of the two factors in which signs of tongue loadings were reversed from the original. Segments which have a positive loading for this factor have a retracted tongue root, mainly at the pocket of the epiglottis, and a somewhat lowered rear dorsum. For the two vowel sets, it produces a continuum from /u/ to /ɑ/. It almost separates [±ATR] vowels and retracted from non-retracted vowels, but this back continuum has difficulty with the mid and low front vowels /e/ and [æ]. Although these vowels do not fit into a scale among back vowels, they may have some retraction due to lowering, but less than would be expected for [-ATR]. In both cases, [e] is on the expected side of [ɛ] and [æ] is on the expected side of [ɑ]. In Arabic (5) (and in Arabic (3) included for comparison), it separates the retracted alveolars from the other consonants. In Arabic (5), /k/ and /q/ head the other end of the continuum, while the pharyngeals and plain alveolars hover around zero.

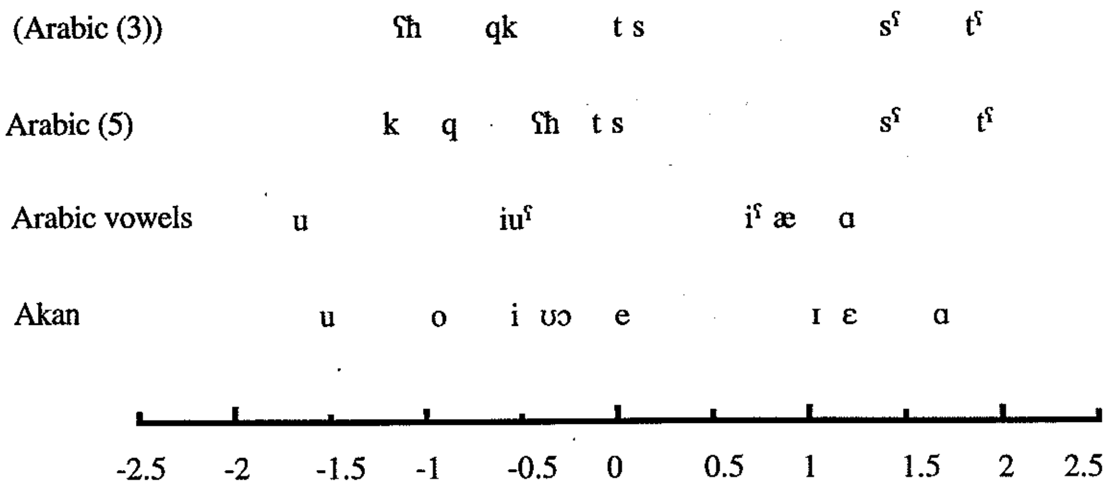
The only data set to rank the Dorsal Constriction Factor (T4) highly, shown in (7-37), is Arabic vowels. The Dorsal Constriction Factor (T4) is correlated with the Upper Pharyngeal Constriction Factor (T1) at -0.847, and the other data sets rank the Upper Pharyngeal Constriction Factor (T1) more highly. In Arabic vowels, it separates retracted vowels from non-retracted vowels. Notice in Akan that it would separate back vowels from front vowels, suggesting that different patterns of movement are used for the retracted/non-retracted and [±ATR] dichotomies. In both Arabic consonant solutions, presented only for comparison, this factor to some extent separates consonants with a retracted or pharyngeal component from those which do not. In both data sets, there is a plain alveolar mixed in with the backer consonants: /s/ for Arabic (5) and /t/ for Arabic (3).



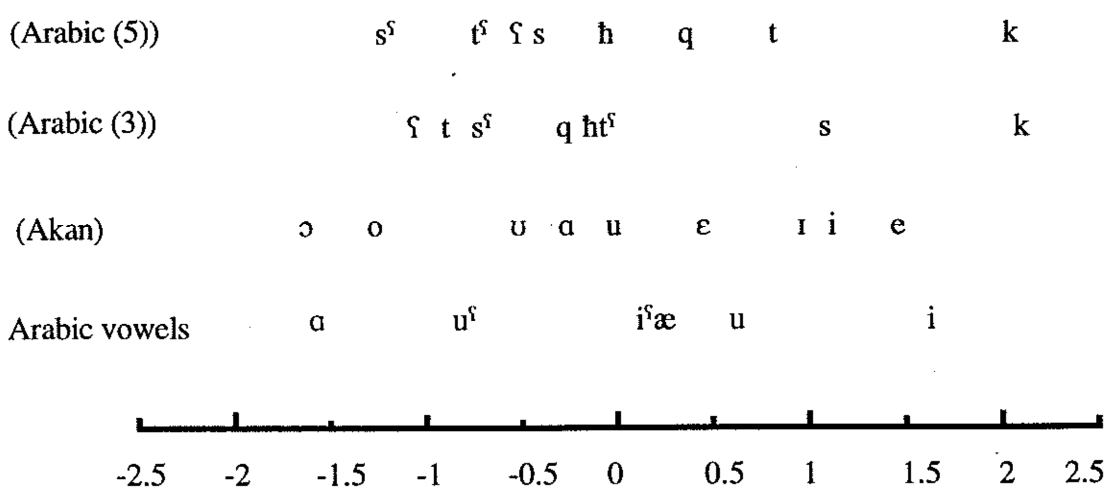
(7-34) Segment loadings for the Upper Pharyngeal Constriction Factor (T1). Arabic (3) refers to the three-speaker solution and Arabic (5) refers to the five-speaker solution. As this factor is correlated with T4 for Arabic vowels, this data set is included only for comparison. In Akan, T1 separates front vowels from back vowels. It appears to do the same in Arabic, but has difficulty with low vowels. The back-component models /q/ well in Arabic. It is also retained by Ndut/!Xóõ.



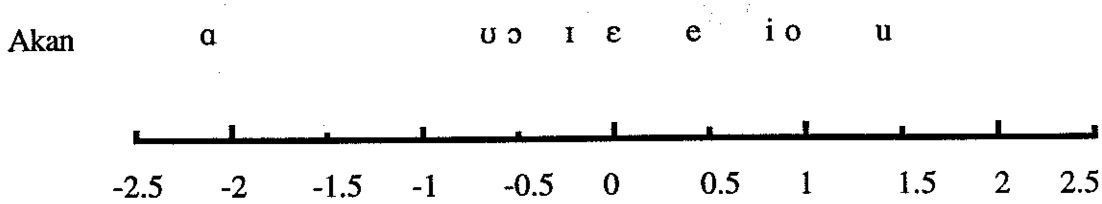
(7-35) Segment loadings for the Laryngopharyngeal Constriction Factor (T2). The two data-sets which retain T2 are the three-speaker Arabic consonant solution and Ndut /!Xóõ. The other solutions weight T3 higher, but are listed here for purposes of comparison. This factor separates pharyngeal from non-pharyngeal consonants, and the low vowel /ɑ/ in Arabic (but not in Akan).



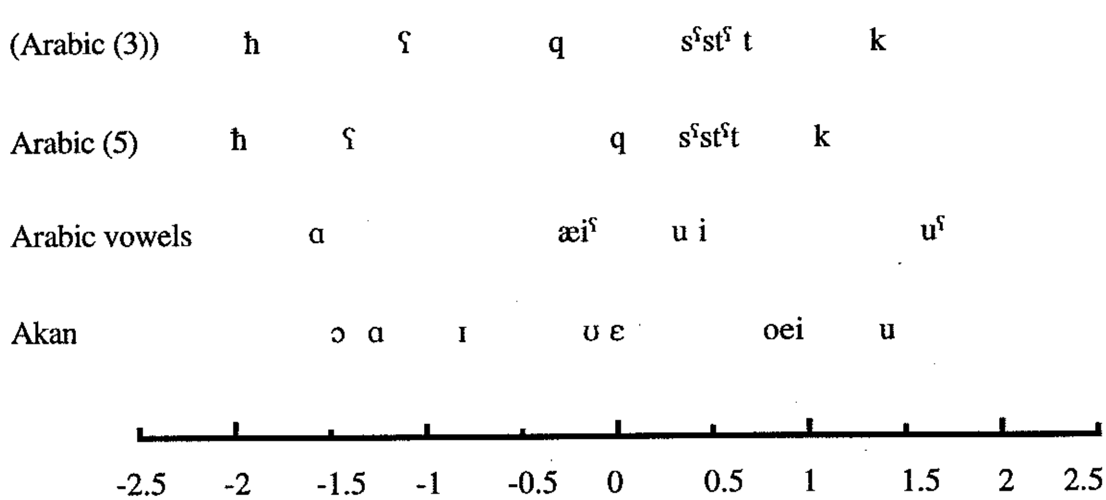
(7-36) Segment loadings for the Radical Constriction Factor (T3). Arabic (3) loadings are included only for comparison as it ranks T2, with which T3 is correlated, more highly. This factor separates the retracted alveolars from other consonants in both Arabic data sets. It almost separates [±ATR] vowels and retracted from non-retracted vowels.



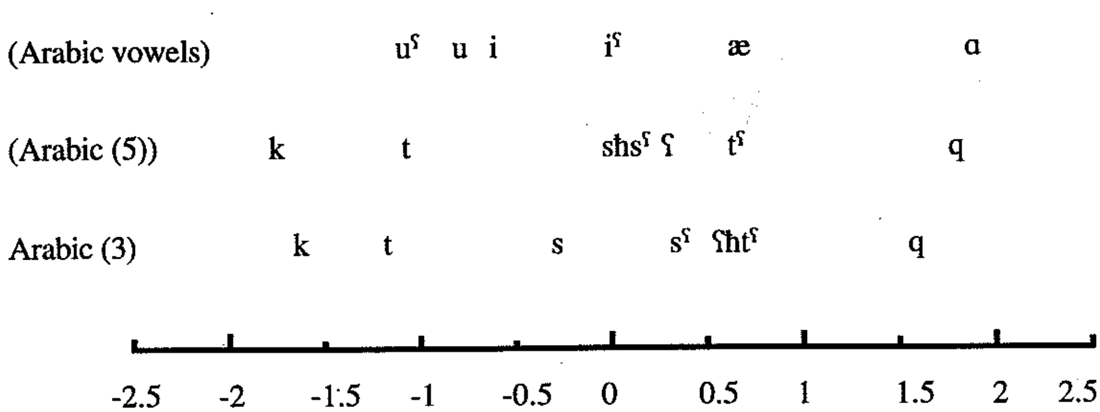
(7-37) Segment loadings for the Dorsal Constriction Factor (T4). Arabic vowels are the only data set to weight T4 highly. It separates retracted vowels from non-retracted vowels. The remaining language data sets rank it below T1, with which it is correlated, and they are included only for comparison.



(7-38) Segment loadings for the Larynx Raising Factor (P2). Akan and Ndut/!Xóõ (no segment data) are the only data sets to weight this factor highly. This factor, along with P4, separates [±ATR] vowels.



(7-39) Segment loadings for the Pharynx Expansion Factor (P4). Arabic (3) is included for comparison, although that data set weights factor P5 more highly. This factor separates [±ATR] vowels and pharyngeal consonants from non-pharyngeal consonants.



(7-40) Segment loadings for the Pharynx Shifting Factor (P5). The three-speaker Arabic data set is the only one to weight this factor highly. The other two Arabic data sets rank factor P4 more highly, and are included for comparison only. In the Arabic consonant data sets, this factor separates those segments which have a pharyngeal component from those that do not. In the Arabic vowel data set, it would separate low from non-low vowels.

Only two data sets, Akan and Ndut/!Xóõ, rank the Larynx Raising Factor (P2) highly, shown in (7-38) (there is no segment data for Ndut/!Xóõ). This factor, along with the Pharynx Expansion Factor (P4), separates [±ATR] vowels in Akan. In P2 (the other factor with reversed signs from the original), the larynx is lowered greatly while the pharyngeal wall advances slightly. In the Pharynx Expansion Factor (P4) (7-39), lowering of the larynx is accompanied by substantial retraction of the pharyngeal wall. In combination, the net result would be to fine tune the amount of pharyngeal wall movement (by lessening the amount of retraction) while the larynx is greatly lowered. When we look at (7-38) and (7-39), we find that the [-ATR] vowels vary the most on these two factors. /ʊ/ and /ɑ/ use less of the Pharynx Expansion Factor (P4) and more of the Larynx Raising Factor (P2), resulting in a high larynx position combined with less pharynx wall constriction. /ɪ/ and /ɔ/ use less of the Larynx Raising Factor (P2) and more of the Pharynx Expansion Factor (P4), giving them a high larynx position with more pharyngeal wall constriction.

The Pharynx Expansion Factor (P4) (7-39) is ranked highly not only by Akan, but also by Arabic vowels and Arabic (5) consonants. Arabic (3) consonants are included for comparison. For both sets of Arabic consonants, this factor separates the two pharyngeal consonants /ħ/ and /ʕ/ from the other consonants. The two pharyngeal segments have raised larynges and advanced (or constricted) pharyngeal walls. The uvular consonant /q/ hovers around zero while /k/ has the highest positive loading, i.e. the greatest amount of laryngeal lowering and the least amount of pharyngeal wall constriction. Note that the plain and retracted alveolars are not separated by this factor, but remain best distinguished by a tongue factor (the Radical Constriction Factor (T3)) rather than a pharynx factor. For Arabic vowels, /ɑ/ has a similar loading to /ʕ/ and /uˤ/ has a similar loading to Akan /u/ and Arabic /k/.

The last factor to be discussed, the Pharynx Shifting Factor (P5) (7-40), is ranked highly only by Arabic (3). Arabic (5) and Arabic vowels are included on (7-40) for comparison. In both Arabic consonant data sets, this factor separates those segments with a pharyngeal component from those that do not. The uvular stop [q] has the greatest loading on this factor (shared with the backed low allophone [ɑ].) The separation in Arabic (3) is somewhat better than for Arabic (5) (which ranks the Pharynx Expansion Factor (P4) more highly). In this instance, the segments with a pharyngeal component have a raised larynx but a less-constricted, or wider, pharynx.

Let us examine what the minimum number of factors retained by each data set do. The Akan data set retained the Upper Pharyngeal Constriction Factor (T1), which separates front and back vowels, the Radical Constriction Factor (T3), which almost separates [±ATR] vowels, the Larynx Raising Factor (P2) and the Pharynx Expansion

Factor (P4), which separate [±ATR] vowels but each in a slightly different continuum. The Arabic vowel data set retained the Dorsal Constriction Factor (T4), which separates retracted from non-retracted vowels, the Radical Constriction Factor (T3), which models [ɑ] and [u] at each end of the continuum and almost separates retracted from non-retracted vowels, and the Pharynx Expansion Factor (P4), which models [ɑ] at one endpoint as similar to [ħ, ʕ] and [uˤ] at the other, as similar to [k]. Both the Arabic (3) and Arabic (5) data sets retained the Upper Pharyngeal Constriction Factor (T1), which models [q] well, but otherwise selected separate factors. The Arabic (3) data set retained the Laryngopharyngeal Constriction Factor (T2), which models the pharyngeal consonants, and the Pharynx Shifting Factor (P5), which splits [k] from [q]. Notice that in this minimum set of factors, the retracted alveolars [tˤ, sˤ] are not distinctively modelled. In the Laryngopharyngeal Constriction Factor (T2), the opposite movement from the pharyngeals models [k], and the retracted alveolars use some of the same movement as [k], a raised tongue dorsum under the hard palate. They also share in the pharyngeal/laryngeal movement of the Pharynx Shifting Factor (P5) with the pharyngeal consonants, which gives a raised larynx with retraction of the pharyngeal wall (widening the pharynx). The Arabic (5) data set retained the Radical Constriction Factor (T3), which distinguishes the retracted alveolars [tˤ, sˤ] from [k, q], and P4, which separates the pharyngeals from other segments. The Ndut/Xóõ data set retained the Upper Pharyngeal Constriction Factor (T1), raised front dorsum vs. raised rear dorsum, the Laryngopharyngeal Constriction Factor (T2), retracted tongue root vs. raised dorsum under the palate, and the Larynx Raising Factor (P2), raised larynx combined with small retraction of the dorsal pharyngeal wall.

Measured by R^2, the partitioned factors do not model the individual languages as well as the factors derived in the language-specific analyses. In most cases, the R^2 of three or four partitioned factors would be less than .60, while in the analyses presented in Chapters 4, 5 and 6, the R^2 for the optimum solutions ranged from .73 to .89. There is a gap in the goodness of fit, but what is interesting to ask is, given this selection of factors derived from the combined data sets, would the same factors be used to model different linguistic categories?

7.6 Comparison of partitioned factors in terms of linguistic categories

[ATR]: [±ATR] segments are modelled by the Larynx Raising Factor (P2) and the Pharynx Expansion Factor (P4) and partially by the Radical Constriction Factor (T3) (/e/ is out of place). P2 and P4 together would cause [+ATR] segments to have a very low larynx and the pharyngeal wall would be retracted on the whole, widening the pharynx. The reverse would be true of [-ATR] segments. The Larynx Raising Factor (P2) is one of the three factors selected by the Ndut/!Xóõ backward-stepping analysis, and perhaps helps distinguish [±ATR] vowels in Ndut. Two other categories also make use of the Pharynx Expansion Factor (P4): Arabic /ɑ/ and the pharyngeal segments /ħ/ and /ʕ/ (Arabic (5)) both have very high larynges and constricted pharynges. The Radical Constriction Factor (T3) displays movement mainly at the pocket of the epiglottis; a [+ATR] segment would have an advanced tongue root and a [-ATR] segment would have a retracted tongue root. Arabic /ɑ/ and the retracted alveolars /sˤ/ and /tˤ/ for Arabic (5) also make use of the Radical Constriction Factor (T3).

Pharyngeal consonants /ħ/ and /ʕ/: These segments are primarily modelled by the Laryngopharyngeal Constriction Factor (T2) for the Arabic (3) data set and the Pharynx Expansion Factor (P4) for the Arabic (5) data set, although each data set makes use of both factors in the best backward-stepping analysis before all correlated factors were removed. The Laryngopharyngeal Constriction Factor (T2) displays retraction of the tongue root from the tip of the epiglottis down to the larynx. Arabic /ɑ/ would also load highly on this factor if allowed to retain it in the backward-stepping analysis. The Laryngopharyngeal Constriction Factor (T2) is the factor weighted most highly by the Ndut/!Xóõ backward-stepping analysis and presumably helps distinguish the low, pharyngealized vowels of !Xóõ. The Pharynx Expansion Factor (P4) focuses on constriction of the pharynx by the raising of the larynx and advancement of the pharyngeal wall. The Pharynx Expansion Factor (P4) was dropped late in the backward-stepping analysis of the Arabic (3) data set and caused a 2.9% reduction in fit.

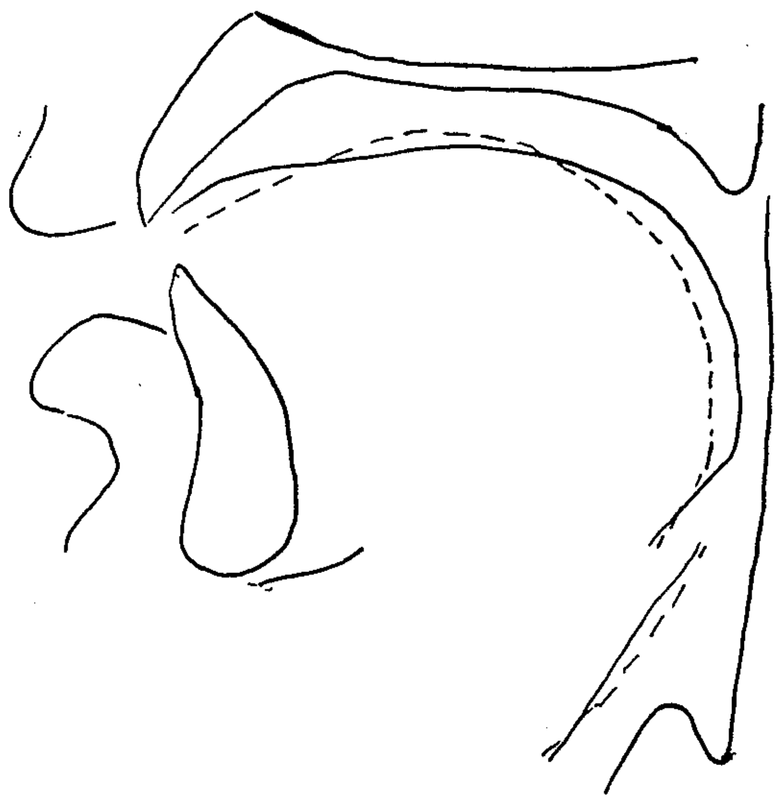
Uvular stop [q]: This segment has the highest loadings on the Upper Pharyngeal Constriction Factor (T1) and the Pharynx Shifting Factor (P5) and a lesser loading on the Radical Constriction Factor (T3). In the Upper Pharyngeal Constriction Factor (T1), the rear dorsum and tongue root are retracted in a broad movement beginning under the soft palate and continuing to the pocket of the epiglottis. The Radical Constriction Factor (T3) accentuates retraction towards the uvula and subtracts some tongue root retraction at the pocket of the epiglottis. The Pharynx Shifting Factor (P5) provides for retraction of the pharyngeal wall (thus widening the pharyngeal cavity) and raising of the larynx. The Upper Pharyngeal Constriction Factor (T1) separates [±back] vowels in Akan. The Laryngopharyngeal Constriction Factor (T2) separates out [ɑ] and the retracted alveolars [tˤ, sˤ] with an opposite loading from [q]: the former segments have more tongue root retraction and less rear dorsum retraction. The Pharynx Shifting Factor (P5) displays retraction of the pharyngeal wall and raising of the larynx and separates segments with a pharyngeal component ([q, tˤ, ħ, ʕ, sˤ]) from those which do not; [q] has the highest loading among the five back segments. It is important to note that [q] does not load highly on the Dorsal Constriction Factor (T4), which is fairly similar to the Upper Pharyngeal Constriction Factor (T1) except for the direction of movement of the tongue root. In the Dorsal Constriction Factor (T4) the tongue root is advanced while the rear dorsum is retracted, while in the Upper Pharyngeal Constriction Factor (T1), the tongue root is retracted along with the rear dorsum.

Retracted alveolars /sˤ/ and /tˤ/: Factors from the combined PARAFAC analysis did not fit the tongue movement of emphatic coronals in the three-speaker data set well (in the backward-stepping analyses), and the original PARAFAC seems better indicative of actual tongue movement. Using the partitioned factors, these segments can best be modelled in the Arabic (5) data set by the Radical Constriction Factor (T3), or retraction at the pocket of the epiglottis (less advancement of tongue root in the Laryngopharyngeal Constriction Factor (T2) and the Upper Pharyngeal Constriction Factor (T1)), while they are best modelled in the Arabic (3) data set by the Pharynx Shifting Factor (P5), in which they are grouped with the pharyngeals /ħ/ and /ʕ/ and the uvular /q/. The Pharynx Shifting Factor (P5) shows a raised larynx but a wider pharynx (through retraction of the pharyngeal wall) for these segments. Arabic (3) is the only data set to make use of the Pharynx Shifting Factor (P5), but this result is similar to what we found in the original solution (See §5.5.2), in which the third factor of that analysis also displayed retraction of the pharyngeal wall for these segments. As is the case above, each data set makes use of both factors in the best backward-stepping analysis before all correlated factors were removed.

PARAFAC is designed to fit movements which account for the greatest percentage of variance first. Retracted coronals, which account for only a small proportion of the combined data set of four languages, appear to have been fit more or less with what was already available. If we compare models of /sˤ, tˤ/ using factors from the Arabic (3) data set analysis and using partitioned factors T3, T2, and T1, we find three main differences. Loadings for both segments are given in (7-41) and the loadings are plotted in (7-42) for /$s^ʕ$/ and (7-43) for /$t^ʕ$/. The first difference is the amount of tip raising. Tip raising in /$s^ʕ$, $t^ʕ$/ is inadequate in the model formed by partitioned factors T3, T2 and T1, whereas it appears quite reasonable in the model formed from Factors 1-3 in the Arabic (3) analysis. The second difference is the profile of the tongue under the palate: flat or concave for Arabic (3) factors but convex for the partitioned factors. Lowering of the palatine dorsum was reported by Ghazeli (1977). The third difference is the location of constriction in the pharynx. The retraction is higher in the pharynx in the Arabic (3) model (at gridlines 5 and 6, between the tip of the epiglottis and the uvula) than in the partitioned factor model (at gridline 4, the pocket of the epiglottis). The lower measure of goodness-of fit (R^2) for partitioned factors (.69 vs. .81) suggests that the coronals were fit with the next closest factor which already accounted for a large proportion of variance, in this case the Radical Constriction Factor (T3), used for Akan tongue root movement. In short, the partitioned factors do not model the retracted coronals well, and we will use the model of the Arabic (3) factor analysis which shows retraction to be in the upper pharynx for these factors.

(7-41) Calculations of models for segments /$s^{ʕ}$, $t^{ʕ}$/ for speaker Ali. For each point, (Factor 1xsegment loadingxspeaker loading) + (Factor 2xsegment loadingxspeaker loading) + (Factor 3xsegment loadingxspeaker loading) = deviation from mean for that segment and speaker at a given point. The point of maximum retraction in the pharynx is in bold type.

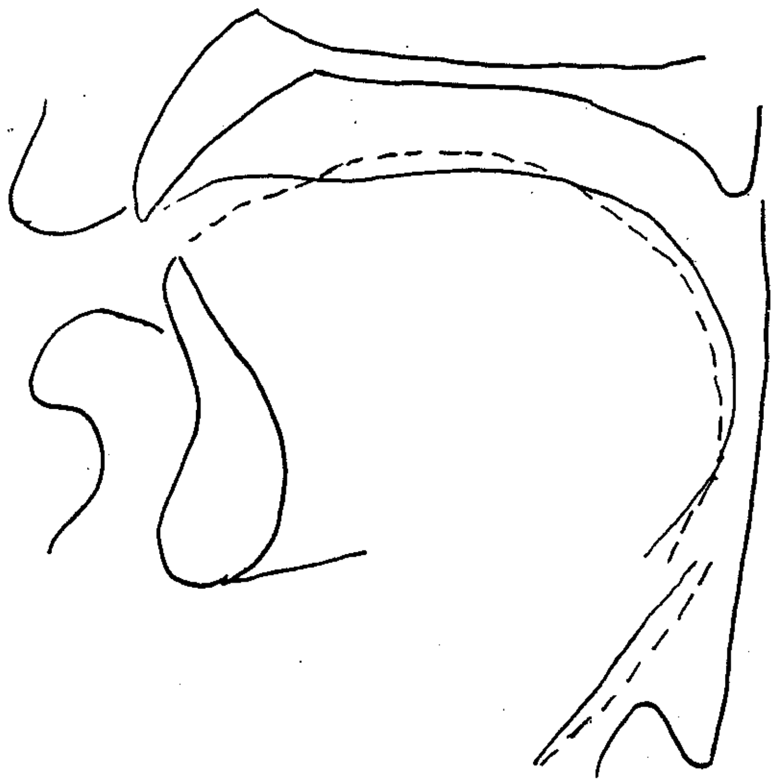
measurement	/$s^{ʕ}$/		/ $t^{ʕ}$/	
point	Arabic (3)	T3+T2+T1	Arabic (3)	T3+T2+T1
e1 (laryngopharynx)	-2.28	-2.34	-0.95	-0.4
e2	-1.45	-0.18	-0.35	2.51
e3	-1.19	0.76	0.41	3.53
e4 (epiglottis)	0.38	1.39	2.49	4.28
t4 (epiglottis)	0.81	**2.44**	2.79	**5.62**
t5	3.34	2.15	**4.98**	4.97
t6	**3.41**	0.60	4.75	2.73
t7	2.71	-0.54	3.04	0.75
t8 (uvula)	2.06	-1.74	1.46	-0.95
t9	0.25	-1.63	-0.80	-1.66
t10	-0.55	-0.93	-2.63	-1.89
t11	-0.84	1.21	-3.41	-0.99
t12	-0.64	2.20	-3.30	-0.27
t13	-0.05	2.16	-2.50	0
t14	2.45	2.41	0.72	0.06
t15	5.54	2.32	5.03	0.68
t16 (apex)	6.56	3.25	6.69	1.40



(7-42) Reconstructions of Arabic [$s^{ʕ}$].

----- Reconstruction from partitioned factors.

___ Reconstruction from Arabic (3) factors



(7-43) Reconstructions of Arabic [$t^{ʕ}$].

----- Reconstruction from partitioned factors.

___ Reconstruction from Arabic (3) factors

Retracted vowels /$i^ʕ$/, /ɑ/, /$u^ʕ$/: These vowels are best modeled by the Dorsal Constriction Factor (T4). Tthe Arabic vowel set is the only data set to rank this factor highly. The Dorsal Constriction Factor (T4) shows retraction of the upper tongue root and rear dorsum of the tongue from above the pocket of the epiglottis to the uvula. As shown by the Akan loadings included in (7-37), these segments are more comparable to [+back] vowels in Akan rather than to [-ATR] vowels.

Low vowel /ɑ/: This vowel is modeled by the Radical Constriction Factor (T3) and the Pharynx Expansion Factor (P4) in both Akan and Arabic. The Radical Constriction Factor (T3) provides for retraction of the tongue root at the pocket of the epiglottis, while the Pharynx Expansion Factor (P4) provides for raising of the larynx and advancement (constriction) of the pharyngeal wall. This overlaps with the factors used to model [-ATR] vowels.

Given this selection of partitioned factors, we find differences in which ones best model different linguistic categories. In terms of constriction locations, there would appear to be four. The retracted vowels show retraction from the soft palate to the tip of the epiglottis (the Dorsal Constriction Factor (T4)) and [q] displays a more extensive constriction from the soft palate to the pocket of the epiglottis (the Upper Pharyngeal Constriction Factor (T1)); the retracted alveolars display a constriction in the upper pharynx between the uvula and the tip of the epiglottis (Arabic (3)); [-ATR] vowels and the low vowel /ɑ/ show retraction from the pocket to the tip of the epiglottis (the Radical Constriction Factor (T3)); the pharyngeal consonants (and the low pharyngealized vowels of !Xóõ) require retraction of the tongue root below the pocket of the epiglottis (the Laryngopharyngeal Constriction Factor (T2)). These locations are supported by the individual analyses of each language.

7.7 Summary of the Chapter

In this chapter, we first examined the five factors derived from an analysis of all the data pooled together, using covariance matrices. These factors were then partitioned into two sets: one containing loadings for movement of the tongue, and one containing loadings for larynx and epiglottis height and pharyngeal wall movement. To determine which partitioned factors were most useful for modeling the different language data sets, the partitioned factors were analyzed by PARAFAC against each data set to determine the degree of fit. Factors which contributed little to each data set were removed. In this way we constructed a level playing field, a set of factors derived from all languages present, by which the languages could be more directly compared. For instance, would Arabic pharyngeals be modeled by the same factor(s) as [-ATR] vowels in Akan and Ndut?

The results were summarized in §7.6 above. In general, different linguistic categories made use of different factors. Thus, Arabic pharyngeals and [-ATR] vowels in Akan used different factors to represent tongue movement, although they did use the same factor for movement of the pharyngeal wall and larynx. The retracted vowels in Arabic and [-ATR] vowels are modeled by different factors. The low vowel /ɑ/ is modeled by the same factors in both Akan and Arabic. The tongue factor is the same as for [-ATR] vowels, and is not the one used for pharyngeal consonants. The retracted alveolars were not modeled well by any of the partitioned tongue factors.

CHAPTER 8 GENERAL DISCUSSION AND CONCLUSION: MODELING ARTICULATIONS IN THE PHARYNX

8.0 Overview

In this dissertation, we have examined data on nine classes of sounds which are articulated in the pharynx from four languages: pharyngeal consonants [ħ, ʕ] in Arabic, uvular consonant [q] in Arabic, emphatic coronals [tˤ, sˤ] in Arabic, [+ATR] vowels [i, e, o, u, ə] in Akan and Ndut[1], [-ATR] vowels [ɪ, ɛ, ɑ, ɔ, ʊ] in Akan and Ndut, low vowels [æ, a, ɑ] in all four languages, pharyngealized vowels [uˤ, oˤ, ɑˤ] in !Xóõ, strident vowels [uʢ, oʢ, ɑʢ] in !Xóõ, and retracted vowels [iˤ, a/ɑ, uˤ] derived from pharyngealized coronals in Arabic.

This study was undertaken in order to determine the basic gestures used in forming articulations in the pharynx, to give us an understanding of how these gestures are organized in different languages, and to compare gestures used in different languages to provide a basis for improved feature representation. Through individual language analyses we have examined how each segment type is produced within a given language. These individual language analyses show the coordinated sets of gestures necessary to produce a given segment in a given language. The potential components for each segment articulated in the pharynx include movements of the different parts of the dorsum of the tongue, the tongue root, the tubercle of the epiglottis, the tip of the epiglottis, laryngeal structures, and the pharyngeal wall. In addition, the jaw might be lowered, which is approximated in our measurements by wider lip aperture. For all segments we have been interested in identifying the active articulator and location of constriction for purposes of classification, as well as identifying actions of coordinative

[1] [ə] is found in Ndut while [o] is found in Akan.

structures and other components. In the backward-stepping analyses, we started from a set of factors derived from all speakers with complete data sets. We hypothesized that by separating tongue loadings from larynx and pharyngeal wall loadings we might find fewer distinct patterns of movement which in combination yielded different factors. We were also able to evaluate the importance of tongue or pharyngeal wall/larynx movement in the production of different segments. Using factors derived from all speakers allows us to make more direct comparisons between languages and enables us to begin a classification of segments in terms of articulatory similarity.

In the first section below, we will review the structures and articulatory gestures used to produce segments within a language. We will rely mainly on the PARAFAC analyses of individual languages presented in Chapters 4-6. We will use the results of backward-stepping analyses to evaluate our conclusions and further explicate the importance of certain gestures in individual languages.

In the second section we will use results of the backward-stepping analyses (Chapter 7) to determine which segments might be argued to form a class in terms of articulatory similarity, and thus arrive at a taxonomy of segments in terms of articulators and location. We will compare this classification with previous ones. In the third section, we will examine this classification in light of phonological behavior.

8.1 Articulatory gestures and structures

Below we will review results as a whole for each segment class, while referring to figures (8-1) to (8-20), the articulatory displacements generated by each factor in our earlier analyses. PARAFAC analyses of individual languages show us the coordinative articulatory gestures and coordinative structures used for each segment. The backward-stepping analyses in Chapter 7 allow us to examine some of the components of these gestures.

8.1.1 Pharyngeal consonants [ħ, ʕ] in Arabic

Due to the larger amount of missing data in the Arabic (5) data set, as discussed in §5.6.1, we regard the Arabic (3) data set results to be superior to the Arabic (5) results[2]. In the analysis of three speakers of Arabic, these segments are formed by almost equal (and in both cases, negative)[3] amounts of two factors (Arabic (3) Factors 2 (8-7) and 3 (8-8)). The movement modeled by these two factors yields pharyngeal segments in which there is an even degree of constriction from the tip of the epiglottis to the larynx. The blade and dorsum are lowered yielding a low tongue body position. The lip aperture is widened, so we infer that the jaw is lowered. In comparison with [-ATR] vowels in Akan (8-2), the tongue root in the pharyngeal consonants shows less overall movement, more movement in the laryngopharynx, and less movement in the mid pharynx above the tip of the epiglottis. In fact, the rear dorsum is actively advanced in the production of the pharyngeal consonants. This helps produce a pyramidal shape plus sulcalization of the dorsum (noted by Ghazeli, 1977 and Delattre, 1971). The larynx is raised for both pharyngeal segments in the three-speaker data set. The pharyngeal wall does not contribute to constricting the pharynx in the Arabic (3) data set, as there are almost equal contradictory movements of the pharyngeal wall in Factors 2 and 3.

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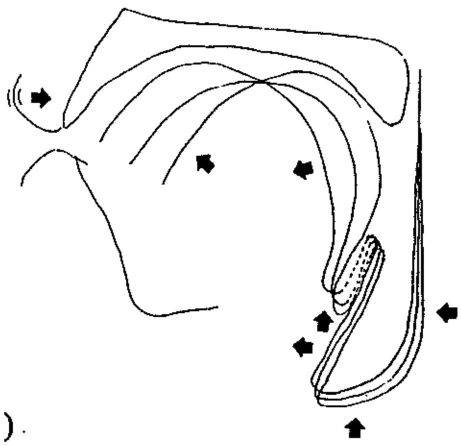
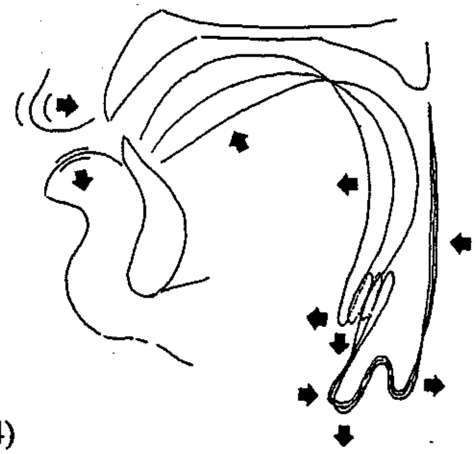
[2]Arabic (3) refers to the Arabic three-speaker data set, consisting of one Tunisian speaker, one Iraqi speaker and one Qatari speaker from Ghazali (no date), Ali (no date) and Bukshaisha (1985) (see §5.5.1). Arabic (5) refers to the Arabic five-speaker data set, and consists of one Tunisian speaker, two Iraqi speakers and two Syrian speakers from Ghazali (no date), Ali (no date), Al-Ani (1970) and Ferguson & Abramson (1962) (see §5.6.1).
[3]Negative loadings reflect movement in the opposite direction of the arrows on the figures.



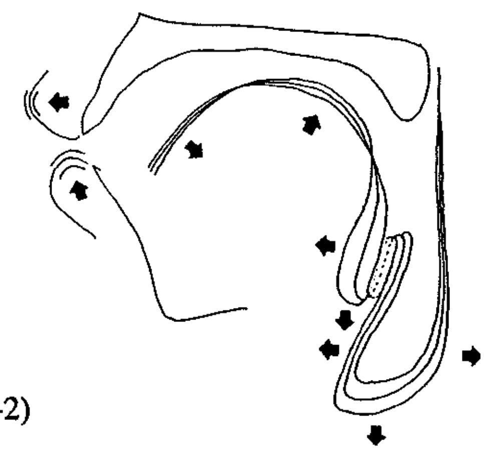
(8-1)

Akan Factor 1



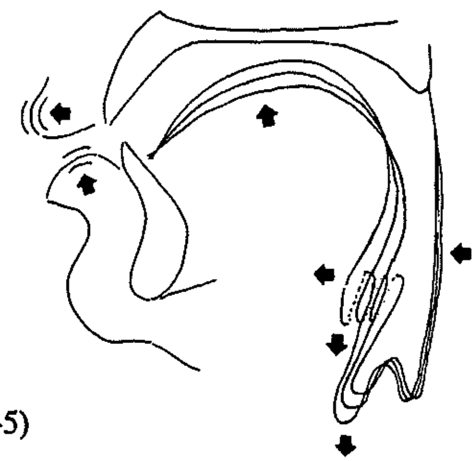
(8-4)

Arabic Vowel Factor 1



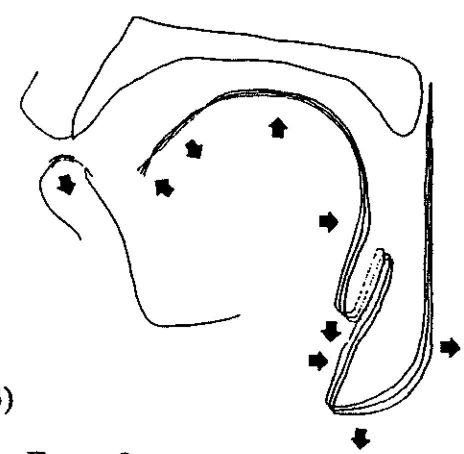
(8-2)

Akan Factor 2



(8-5)

Arabic Vowel Factor 2

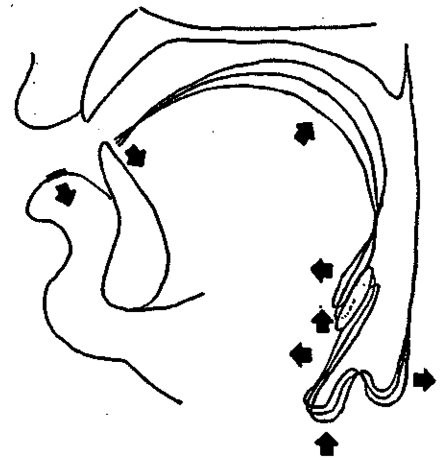


(8-3)

Akan Factor 3

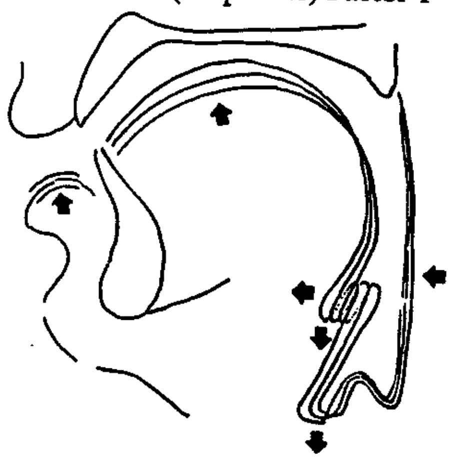
(8-6)

Arabic Consonant (3 Speaker) Factor 1



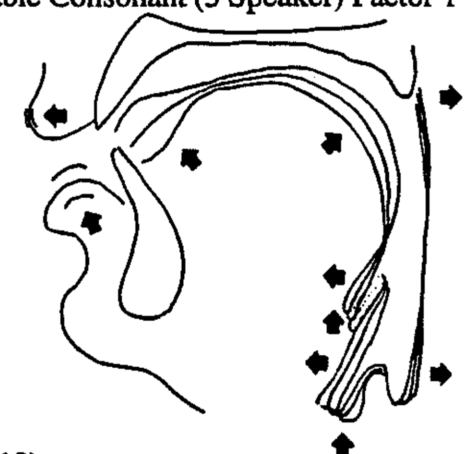
(8-9)

Arabic Consonant (5 Speaker) Factor 1



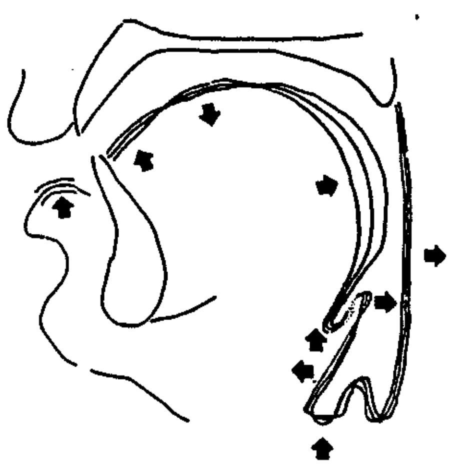
(8-7)

Arabic Consonant (3 Speaker) Factor 2



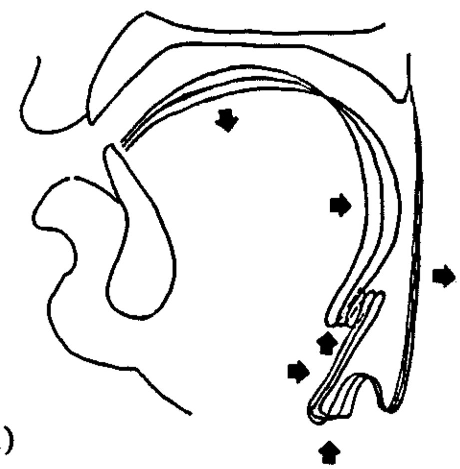
(8-10)

Arabic Consonant (5 Speaker) Factor 2



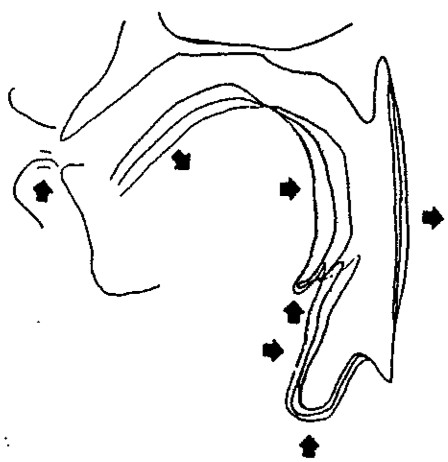
(8-8)

Arabic Consonant (3 Speaker) Factor 3



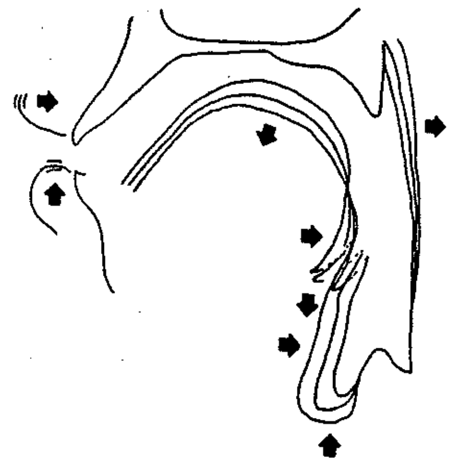
(8-11)

Arabic Consonant (5 Speaker) Factor 3



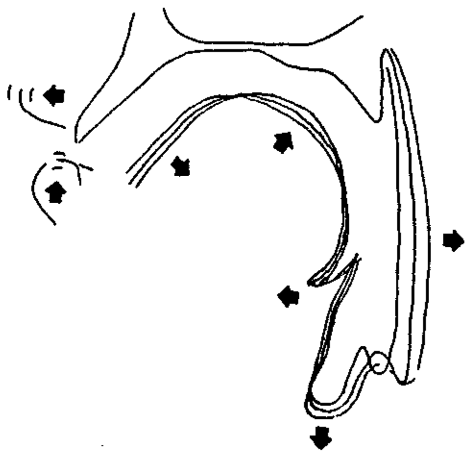
(8-12)

Ndut/!Xóõ Factor 1



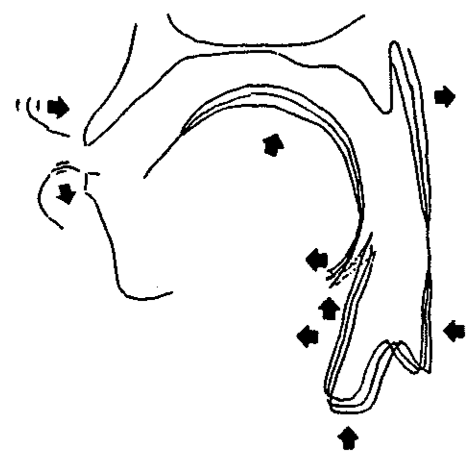
(8-13)

Ndut/!Xóõ Factor 2



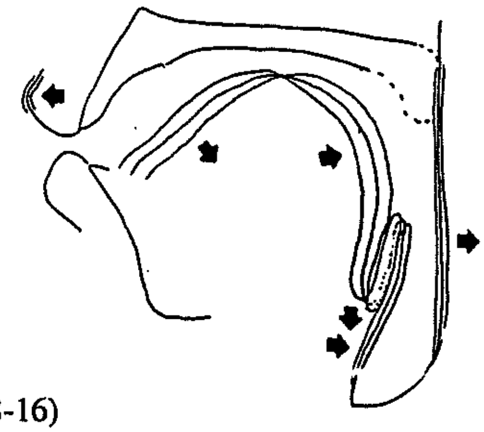
(8-14)

Ndut/!Xóõ Factor 3



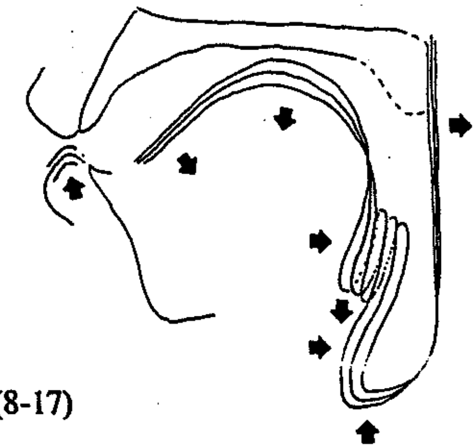
(8-15)

Ndut/!Xóõ Factor 4



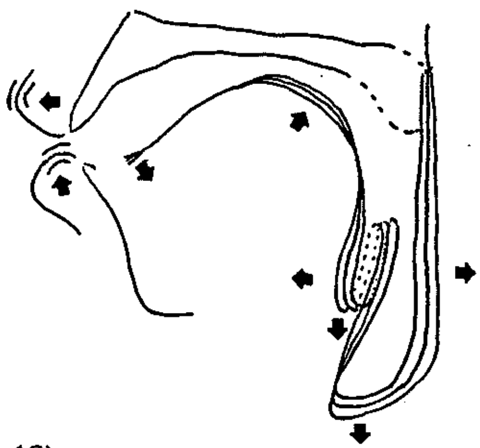
(8-16)

Combined Analysis Factor 1 (=T1 & P1)



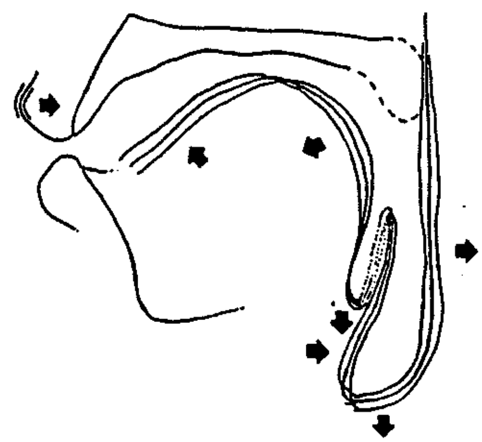
(8-17)

Combined Analysis Factor 2 (=T2 & P2)



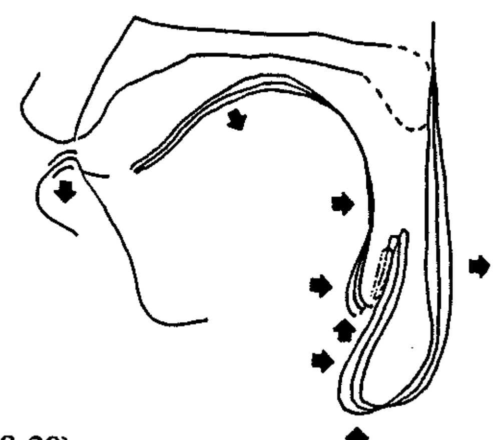
(8-18)

Combined Analysis Factor 3 (=T3 & P3)



(8-19)

Combined Analysis Factor 4 (=T4 & P4)



(8-20)

Combined Analysis Factor 5 (=T5 & P5)

Whereas the PARAFAC Arabic (3) solution did not separate the pharyngeal consonants from other segments, the Laryngopharyngeal Constriction Factor (T2) (8-17), which excludes movement of the larynx and pharyngeal wall, does distinguish the pharyngeal consonants [ʕ, ħ] from the other consonants. The tongue movements in the Laryngopharyngeal Constriction Factor are very similar to the factors which model the pharyngeal segments in both Arabic (3) and Arabic (5) analyses (Factor 2 in both cases). The tongue root is evenly retracted from the tip of the epiglottis to the bottom of the laryngopharynx. The larynx/pharyngeal wall component of pharyngeal consonants is modeled by the Pharynx Expansion Factor (P4) (8-20) in which the larynx is raised and the pharyngeal wall advanced. While the pharyngeal wall is advanced, further restricting the airspace, it is not as advanced as in Akan. Raising of the larynx is more important to the pharyngeal consonants than movement of the pharyngeal wall.

For the pharyngeal consonants, the active articulator is the tongue root. The production of pharyngeal consonants involves both a constriction against the back wall of the pharynx as well as one between the tubercle of the epiglottis and the upper structures of the larynx. The constriction begins at the level of the pocket of the epiglottis and continues down to the larynx.

8.1.2 Uvular stop [q] in Arabic

In both Arabic consonant solutions, [q] loads highly on two different factors: one which displays tongue raising under the soft palate (in both cases, the first factor) and one which shows tongue retraction in the upper pharynx below the uvula (the third factor in both cases). (Relative weights of factors are graphed in (5-14) and (5-22).) Retraction of the rear dorsum into the upper pharynx is accompanied by retraction of the rear wall of the pharynx in both instances (causing widening of the pharyngeal airspace).

The larynx is raised by both factors in both data sets. Lip aperture is widened more in the Arabic (3) data set than in the Arabic (5) data set.

For /q/, the length of the pharyngeal constriction is somewhat different in the individual language analyses (Arabic (3) and Arabic (5); as shown by the third factors in both data sets) as compared with the Upper Pharyngeal Constriction Factor (T1) selected in the backward-stepping analyses of partitioned factors. In (8-8) and (8-11), the constriction tapers off markedly at the tip of the epiglottis, while in the Upper Pharyngeal Constriction Factor, it continues down to the pocket of the epiglottis. In this case, the agreement of the two individual language analyses is probably a better indicator of the length of the constriction rather than the Upper Pharyngeal Constriction Factor. The active articulator is still the rear dorsum, with little involvement of the tongue root. Some analyses have sought to explain the length of uvular constrictions as resulting from the use of two articulators or two nodes, usually the rear dorsum and the tongue root or the dorsum and [pharyngeal] nodes (McCarthy, 1994). Since the constriction tapers off just where the tongue root begins (i.e. roughly at the tip of the epiglottis) in the individual analyses, it is unlikely that there is active involvement of the tongue root in this case. The rear dorsum is both backed and raised, making the area of constriction quite broad.

The pharyngeal wall/larynx component is modeled by the Pharynx Shifting Factor (P5)(8-20) for the three-speaker data set. The Pharynx Shifting Factor models a pharynx/larynx movement different from that in Akan: the pharyngeal wall is retracted, widening the airspace, while the larynx is raised. The larynx and the pharyngeal wall do not act in concert to jointly expand or constrict the pharyngeal airspace. This shortening but widening of the pharynx is found in both Arabic (3) Factors 2 and 3, and in Arabic (5) Factor 3. In (7-40), the Pharynx Shifting Factor separates all of the backed segments: [$s^ʕ$, ʕ, ħ, $t^ʕ$, q], but the pharyngeal consonants also use the Pharynx Expansion Factor (P4), which advances the pharyngeal wall. Thus the pharyngeal consonants and [q, $t^ʕ$, $s^ʕ$] share raising of the larynx, but not movement of the pharyngeal wall, which is advanced (constricting the pharynx) for the pharyngeal consonants but retracted (widening the pharynx) for [q, $t^ʕ$, $s^ʕ$].

8.1.3 Emphatic coronals /$t^ʕ$, $s^ʕ$/ in Arabic

In both of the PARAFAC Arabic consonant solutions, these two segments load highest on the factor which displays retraction of the rear dorsum in the upper pharynx between the uvula and the tip of the epiglottis (the third factor in both solutions, (8-8) and (8-11)). In the solution for three speakers, the (secondary) constriction location is slightly closer to the uvula than that in the solution for five speakers. As discussed in §7.6, the partitioned factors from the combined solution do not model the coronals well and we will use factors from the Arabic (3) analysis for the model of tongue movement for the emphatic coronals.

The pharyngeal wall/larynx movement is modeled in the Arabic (3) data set by the Pharynx Shifting Factor (P5)(dorsal wall and larynx portion of (8-20)) for [$s^ʕ$, $t^ʕ$, q]. The Pharynx Shifting Factor displays shortening plus widening of the airspace, together with other backed segments. The tongue gestures are somewhat different for [$s^ʕ$, $t^ʕ$] and [q], but the actions of the larynx and pharyngeal wall are similar. The pharyngeal consonants and [q, $t^ʕ$, $s^ʕ$] share raising of the larynx, but not movement of the pharyngeal wall, which is advanced (constricting the pharynx) for the pharyngeal consonants but retracted (widening the pharynx) for [q, $t^ʕ$, $s^ʕ$].

We have shown that the articulation of [$t^ʕ$, $s^ʕ$] is made in the upper pharynx below the uvula for speakers of Tunisian, Iraqi and Qatari Arabic, while the constriction was shown to be closer to the tip of the epiglottis in the data set of five-speakers, which included two Syrian speakers. A constriction in the upper pharynx agrees with, and generalizes, Ghazeli's 1977 analysis of the same Tunisian data. Ghazeli shows that there is backing in the upper pharynx for all affected segments and a lowered F_2 (where measurable). Lowering of the second formant has been observed in other studies as well (Obrecht, 1968, Al-Ani, 1970, Card, 1983). The unanimity of these studies in finding lowered second formants suggests that this acoustic cue is used over a wide geographical area. The pharyngeal component of emphatic coronals does not seem to have a similar acoustic signature to that of the back constriction of pharyngeal segments and [-ATR] vowels, which are characterized by a relatively higher first formant (Delattre, 1971, Lindau, 1975, Ghazeli, 1977, El-Halees, 1985, Alwan, 1987, Butcher and Ahmad, 1987). The results of the individual Arabic (3) data set and Arabic (5) data set analyses indicate that the emphatic coronals are distinguished by retraction in the upper pharynx, below the uvula but above the tip of the epiglottis, where effect on F_1 would be relatively small.

8.1.4 [±ATR] vowels in Akan and Ndut

The difference between [±ATR] vowels in Akan is modeled by (8-2), Akan Factor 2 (see (4-7)). For [-ATR] vowels, pharyngeal constriction begins midway between the bottom of the uvula and the tip of the epiglottis, and tapers off as it approaches the larynx. Maximum constriction occurs at the pocket of the epiglottis. The constriction also involves raising of the larynx and advancement of the pharyngeal wall. We do not have segment information for the Ndut speaker because of the use of covariance matrices. However, the Ndut speaker loads primarily on Ndut/!Xóõ Factors 1 (8-12) and 3 (8-14) (see also (6-5)). Ndut/!Xóõ Factor 1 (8-12) is similar to Akan Factor 1 (8-

1) in the actions of the front and rear dorsum and tongue root, except the magnitude of movement is not as large. Akan Factor 1 distinguished front and back vowels, and Ndut/!Xóõ Factor 1 presumably does the same in Ndut (and !Xóõ). Ndut/!Xóõ Factor 3 (8-14) displays a huge movement of the pharyngeal wall and a somewhat lesser movement of the larynx which together help expand or constrict the pharynx. The !Xóõ speakers use little of this factor, making it primarily an Ndut factor. Akan Factor 2 (8-2) distinguished [±ATR] vowels and it is quite likely that Ndut/!Xóõ Factor 3 (8-14) does the same for Ndut, given the movements which expand/constrict the pharynx. It is worth noting in Ndut that the largest movement takes place in the pharyngeal wall, while in Akan the largest movements are retraction of the tongue root at the pocket of the epiglottis and raising of larynx. The substantial pharyngeal wall movement found in Ndut/!Xóõ Factor 3 is not reflected in selection of partitioned factor (P2), the Larynx Raising Factor, in the backward-stepping analyses. The fit of Ndut/!Xóõ data to partitioned factors is poor and is complicated by the use of covariance matrices. We will assume that Ndut/!Xóõ Factor 3 is better indicative of [±ATR] movement in Ndut than any of the partitioned factors.

For Akan, the match between Akan Factor 2 (8-2) and the Radical Constriction Factor (T3) (tongue portion of (8-18)) is fairly close, although movement of the tongue root extends both higher and lower in Akan Factor 2 than in the Radical Constriction Factor. In both cases, the segment loadings show [u] on one end and [ɑ] on the other. Akan Factor 2 is able to separate [±ATR] vowels; the Radical Constriction Factor (with tongue movement only) does not quite separate [±ATR] vowels while the Pharynx Expansion Factor (P4) (larynx and pharyngeal wall movement only of (8-19)) does, suggesting that movement of the larynx and pharyngeal wall is crucial in making the [ATR] distinction in Akan. Retraction of the tongue root in both Akan Factor 2 and the

Radical Constriction Factor are centered at the pocket of the epiglottis. This is thus different from the movement of the tongue root in pharyngeal consonants and of the rear dorsum in emphatic coronals.

8.1.5 Low vowels

In Akan, [ɑ] is formed mainly by Akan Factor 2 (8-2), which is the same factor that models [-ATR] vowels. In Arabic, [æ, ɑ] are modeled by Arabic Vowel Factor 2 (8-5), which shows movement of the tongue root and larynx quite similar to that in Akan Factor 2 (8-2). Retraction of the tongue root is greatest for both at the pocket of the epiglottis, but the tapering off of the constriction extends upward to midway between the tip of the epiglottis and the uvula and downward into the laryngopharynx. In Arabic, it does not include movement of the pharyngeal wall and there is also added lowering of the front dorsum. Akan [ɑ] displays greater constriction at the pocket of the epiglottis than does Arabic [ɑ].

These results are supported by the backward-stepping analyses using partitioned factors. In both the Akan and Arabic vowel data sets, /ɑ/ is modeled by retraction of the tongue root at the pocket of the epiglottis found in the Radical Constriction Factor. As above, there is less retraction for /ɑ/ in Arabic than in Akan. In the Arabic vowel data set, /ɑ/ is additionally modeled by negative movement of the Dorsal Constriction Factor, which yields advancement of the tongue root in the laryngopharynx, retraction of the rear dorsum and lowering of the blade and front dorsum.

8.1.6 Pharyngealized vowels [uˤ, oˤ, ɑˤ] and strident vowels [u̢ˤ, o̢ˤ, ɑ̢ˤ] in !Xóõ

These are two separate categories but we do not have segment information on !Xóõ because of the use of covariance matrices. The most important factors for modeling movement in the pharynx for !Xóõ vowels are the Laryngopharyngeal Constriction Factor (T2) and Ndut/!Xóõ Factor 2. Both display retraction of the tongue root extending from the tip of the epiglottis all the way down to the larynx. This is different from the [-ATR] vowels, which display retraction primarily at the pocket of the epiglottis and less movement of the tongue root in the laryngopharynx. The Laryngopharyngeal Constriction Factor also models the pharyngeal consonants [ʕ, ħ] in the Arabic (3) data set, indicating that the laryngopharyngeal constriction is similar in Arabic pharyngeals and !Xóõ pharyngealized/strident vowels.

Ndut/!Xóõ Factor 2 (8-13) displays constriction of the laryngopharynx through raising of the larynx and retraction of the tongue root and tubercle of the epiglottis. The dorsum is lowered and the lip aperture is narrowed slightly (one case where raising of the larynx is not coordinated with opening of the jaw). It is most likely that this factor contributes to the strident vowels which have the most constricted laryngopharynx. We began with three categories of vowels in !Xóõ: plain, including plain [ɑ], pharyngealized and strident, but we have only two factors on which to map them. This makes it likely that the pharyngealized vowels in particular are not distinctively modeled by a separate factor but by different degrees of use of one or both of these factors. In addition, as Ndut/!Xóõ Factor 1 provides only a small amount of constriction in the laryngopharynx, presumably the pharyngealized vowels of !Xóõ would use Ndut/!Xóõ Factor 2 as well, but to a lesser extent than the strident vowels.

8.1.7 Retracted vowels in Arabic [iˤ, ɑ, uˤ]

The retracted vowels in Arabic are not separately modeled by either of the two vowel factors in the PARAFAC analysis of Arabic vowels alone, rather, each retracted vowel uses relatively more of Arabic Vowel Factor 1 (8-4), i.e. more retraction of the rear dorsum, than its unretracted counterpart. There is little involvement of the larynx and pharyngeal wall. The location of the greatest degree of retraction is in the upper pharynx under the uvula, similar to the retraction found in emphatic coronals. In addition, [uˤ] and [ɑ] were shown to have retraction of the tongue root. Thus it would seem that we have found backing for [iˤ], and backing plus lowering for [ɑ, uˤ].

The movement in Arabic Vowel Factor 1 (8-4) is similar to Akan Factor 1 (8-1), which separates front/back vowels in Akan. This is borne out by the backward-stepping analyses, in which the Arabic retracted vs. non-retracted vowels are distinguished by the Dorsal Constriction Factor (T4), the same factor which separates front and back vowels in Akan. The main difference between Arabic vowel Factor 1 and the Dorsal Constriction Factor is in the movement of the tongue root. In the Dorsal Constriction Factor, the tongue root advances slightly as the rear dorsum is retracted, while in Arabic vowel Factor 1, the tongue root moves in the same direction as the rear dorsum.

8.1.8 Summary

Above, we have delineated the articulatory gestures extracted from PARAFAC analyses to model each segment type. We have seen retraction of the rear dorsum in the upper pharynx for uvular consonants and (slightly lower) for emphatic coronals in Arabic, retraction of the tongue root at the pocket of the epiglottis for Akan [-ATR] vowels and low /ɑ/ in both Akan and Arabic, and retraction in the laryngopharynx for pharyngeal consonants in Arabic and strident vowels in !Xóõ. We have seen differing uses of the vertical position of the larynx and the advancement and retraction of the pharyngeal wall in the production of these classes of sounds and different degrees of utilization. Ndut relies on movement of the pharyngeal wall to a greater degree than Akan, while Akan relies more on movement of the larynx and tongue root. There is greater movement of the pharyngeal wall in both Akan and Ndut than in Arabic. Pharyngeal consonants use raising of the larynx but less movement of the pharyngeal wall to enhance the constriction in the laryngopharynx. Uvular [q] and emphatic [$t^ʕ$, $s^ʕ$] also use raising of the larynx, but retraction of the pharyngeal wall, shortening but widening the airspace.

8.2 Comparison of articulatory gestures and coordinative structures across languages

Use of a common set of partitioned factors in the backward-stepping analyses allows us to make more direct comparisons between gestures used in different languages. The partitioned factors used for each segment class are summarized in (8-21):

(8-21) Summary of partitioned factors for modeling each segment class

Pharyngeal [ħ, ʕ] in Arabic:	T2 & P5 (Arabic (3)), P4 (Arabic (5))
Uvular [q] in Arabic:	T1-T3 (Arabic (3), (5)), P5 (Arabic (3))
Emphatic coronals [tˤ, sˤ] in Arabic:	-T2 &P5 (Arabic (3)), T3-T1 (Arabic (5))
	=T3-T2-T1 & P5
[±ATR] vowels in Akan:	P2, P4 (T3 almost)
[±ATR] vowels in Ndut:	T2? P2?
Low vowels:	T3 (Akan, Arabic (3))
Pharyngealized [uˤ, oˤ, ɑˤ] vowels in !Xóõ:	T2?, P2?
Strident vowels [uʢ, oʢ, ɑʢ] in !Xóõ:	T2, P2
Retracted vowels [iˤ, ɑ, uˤ] in Arabic:	T4

Notes:

T1=Upper Pharyngeal Constriction Factor	P2=Larynx Raising Factor
T2=Laryngopharyngeal Constriction Factor	P4=Pharynx Expansion Factor
T3=Radical Constriction Factor	P5=Pharynx Shifting Factor
T4=Dorsal Constriction Factor	

We will first restrict ourselves to the tongue gestures as they are better indicative of the traditional means of classification: active articulator and location. (8-22) shows four locations for consonants and vowels. Two locations are shared by both consonants and vowels: the first in the upper pharynx, and the fourth along the length of the epiglottis. We have termed the fourth location 'laryngopharynx', since there is an equal degree of retraction from the epiglottis to the larynx. The second location is used only by emphatic coronals and interpretation is more complex; however in §7.6 we concluded that the Arabic emphatic coronals have a constriction in the upper pharynx between the uvula and the tip of the epiglottis. In the third location, low vowels in Arabic and the [±ATR] vowels in Akan rely on advancement/retraction at the pocket of the epiglottis.

(8-22) Regrouping in terms of location in pharynx

	Consonants	Vowels
Upper Pharynx	T1-T3 [q]	T4 [iˤ a, uˤ]
Mid Pharynx	T3-T2-T1 [tˤ, sˤ]	
Pocket of Epiglottis		T3 [±ATR] (Akan); [æ, ɑ] (Arabic)
Laryngopharynx	T2 [ħ, ʕ]	T2 [u̙, o̙, ɑ̙]

While place of articulation for [q] and for the retracted vowels [iˤ a, uˤ] is in the upper pharynx, they do not use the same partitioned factor. We can hypothesize that the reason [q] is modelled by T1-T3 rather than T4 is that [q] requires more movement for closure than do the vowels. T1, the Upper Pharyngeal Constriction Factor, displays a greater movement than does T4, the Dorsal Constriction Factor. It may also be that [q] requires a longer constriction - in both the Arabic (3) and Arabic (5) solutions, [q] is modeled by a combination of two factors. The other difference in T1 and T4 is in the coordination of the tongue root movement with dorsal movement. The tongue root is advanced in T4 and retracted in T1.

The movement of the Dorsal Constriction Factor (T4) for the retracted vowels in Arabic is clearly dorsal, as retraction ceases at the epiglottis, and the tongue root is advanced. Maximum constriction is directed towards the velopharyngeal port. The segment loadings in (7-37) show that the Dorsal Constriction Factor (T4) would distinguish front/back vowels in Akan. We can conclude that the articulatory mechanism which distinguished [±ATR] vowels in Akan is not the same as that used by retracted vowels in Arabic.

The second location in the mid-pharynx between the uvula and the tip of the epiglottis is used by the emphatic coronals. The location is slightly lower than the location for [q] and the retracted vowels [iˤ, ɑ, uˤ]. The solid lines in (7-42) and (7-43) show reconstructions of [tˤ, sˤ] where the rear dorsum makes a fairly narrow focal constriction in the mid-pharynx.

The next two locations overlap at the pocket of the epiglottis. Movement of the Radical Constriction Factor (T3) at the pocket of the epiglottis for [±ATR] vowels in Akan and low vowels in both Akan and Arabic agree with the results of the individual language PARAFAC analyses. In earlier chapters it had appeared that pharyngeal consonants in Arabic shared retraction of the tongue root at the epiglottis together with Akan [-ATR] vowels and low vowels. Comparison with results of the backward-stepping analyses show an important difference. The pharyngeal consonants and the !Xóõ vowels, particularly of !Xóõ speaker 1, display retraction of the tongue root from the tip of the epiglottis to the larynx as displayed by the Laryngopharyngeal Constriction Factor (T2), whereas [-ATR] vowels and low vowels show retraction primarily at the pocket of the epiglottis with the Radical Constriction Factor (T3). The difference in location between articulations at the pocket of the epiglottis and in the laryngopharynx is accompanied by different tongue root profiles. The [-ATR] constriction is limited to the pocket of the epiglottis, while the constriction for Arabic pharyngeal consonants [ħ, ʕ] and !Xóõ vowels is extended through the laryngopharynx.

Movements of the larynx and pharyngeal wall are clearly important for some sets of segments. Akan and Ndut [±ATR] vowels and Arabic pharyngeal consonants rely heavily on movements of the larynx and the pharyngeal wall for distinctiveness. The partitioned factors offer three choices: movement of the pharyngeal wall alone as in P1, coordinated movement of the larynx and pharyngeal wall to expand or constrict the pharynx as in P3 and P4, and coordinated movement of the larynx and pharyngeal wall to cause shortening and widening of the pharynx as in P2 and P5. None of the data sets used P1 or P3. Expansion or contraction of the pharyngeal airspace is overwhelmingly important to the distinction of [±ATR] vowels in Akan. The actions of the Pharynx Expansion Factor (P4) are what allows the [+ATR] vowels to be separated from the [-ATR] vowels in Akan. Ndut/!Xóõ Factor 3 (8-14) also displayed an even larger coordinated movement of the pharyngeal wall and larynx to expand/contract the pharynx (used by the Ndut speaker), but this is not reflected in the backward-stepping analyses. The pharyngeal consonants [ʕ, ħ] are distinguished from other consonants in the Arabic data sets by the use of the Pharynx Expansion Factor (raised larynx and constricted pharyngeal wall), although advancement of the pharyngeal wall is diluted by the Pharynx Shifting Factor. The Arabic (3) data set uses the Pharynx Shifting Factor, shortening plus widening of the pharynx, to distinguish [sˤ, tˤ, q] as a class.

In terms of location, there appear to be four overlapping ranges with different foci: the retracted vowels show a narrower movement of the rear dorsum directed at the body of the uvula (Dorsal Constriction Factor (T4)) while [q] displays a more extensive constriction from the soft palate to the pocket of the epiglottis (Upper Pharyngeal Constriction Factor (T1)), the emphatic alveolars [sˤ, tˤ] display a constriction in the upper pharynx between the uvula and the tip of the epiglottis (Arabic (3)); [-ATR] vowels and low vowels show retraction from the tip to the pocket of the epiglottis (Radical Constriction Factor (T3)); while pharyngeal consonants and the low pharyngealized vowels of !Xóõ require retraction of the tongue root below the pocket of the epiglottis (Laryngopharyngeal Constriction Factor (T2)). And, as mentioned above, [-ATR] vowels in Akan and Ndut and pharyngeal consonants require raising of the larynx and advancement of the pharyngeal wall to further constrict the pharynx.

We have thus met the first goal of this dissertation, namely to determine whether or not these different classes of sounds should be described in the same phonetic terms. We have found that the [-ATR] vowels in Akan are articulated in a different way from the emphatic vowels in Arabic, that emphatic segments are not articulated in the same way as pharyngeal consonants in Arabic, and that the pharyngeal consonants involve constriction below the pocket of the epiglottis in the laryngopharynx which is different from the constriction of [-ATR] vowels at the pocket of the epiglottis. The next question we must address is how they should best be represented.

8.3 Feature Specifications

We will first present a simple feature proposal based on the results of the preceding PARAFAC analyses, and then discuss some alternatives. In (8-22) we have four potential locations of articulatory constrictions. Not all of them may be utilized at the same level of analysis, and only a look at the phonologies of relevant languages can answer what the hierarchical relationships among them are. We will also consider other feature systems in light of the results presented in the preceding chapters and summarized here.

Acoustically, the basic division in the pharynx seems to be between the upper pharynx, where retraction of the tongue causes a drop in F_2, and the lower pharynx, where retraction of the tongue root causes a rise in F_1. Accordingly, we propose that the basic node Pharyngeal be subdivided with one value being [upper pharynx] ([up]). The [upper pharynx] ([up]) specification will be used to describe the pharyngeal component in uvular and emphatic coronal segments. While the emphatic coronals display a lower constriction than uvular /q/ in our analyses (i.e. below the uvula but above the pocket of the epiglottis) and have a higher F_1 and/or a lower F_2, we propose to ascribe the difference to the multiple articulation of the emphatic coronals rather than divide the upper pharynx into two regions of articulation. The lower pharynx itself requires two subdivisions to reflect articulatory and phonological categories: [radical] ([rad]) for articulations at the pocket and [laryngopharynx] ([lpx]) for lower articulations. These two divisions of the lower pharynx, [+rad] and [+lpx] are used contrastively in !Xóõ. As discussed earlier, there are two kinds of pharyngealization on vowels in !Xóõ: one at the epiglottis (referred to elsewhere as pharyngealized vowels), and one much lower and involving the aryepiglottic muscles (referred to elsewhere as strident vowels). There is no evidence in the languages analyzed in this study which would show use of 'lower pharynx' as an independent node and we will thus assume that there is a tripartite division of the pharynx.

The [-ATR] vowels in Akan are articulated with retraction of the tongue root centered at the pocket of the epiglottis, which is different from the constriction location of pharyngeal consonants and the strident vowels of !Xóõ. As this constriction is articulated by the tongue root, we propose that [±ATR] vowels be distinguished by the feature specification Pharyngeal-[radical]. Although we cannot reconstruct which factor(s) best represent the !Xóõ pharyngealized vowels due to the use of covariance matrices, since there is a phonological contrast in !Xóõ between pharyngealized vowels and strident vowels, we propose that the pharyngealized vowels also be represented by the feature specification Pharyngeal-[radical].

Representation of plain low vowels is difficult in a system based on place, as there appear to be degree of constriction differences between plain low vowels vs. the [-ATR] vowels of Akan and the pharyngealized vowels of !Xóõ. Given the widespread occurrence of /a/ in languages of the world, /a/ appears to be the basic or unmarked 'pharyngeal' articulation. It is articulated with the tongue root at the pocket of the epiglottis. In many languages without (other) pharyngeals, /a/ only needs to be marked with the feature [+low]. The [ATR] vowel system of languages such as Akan requires the further superimposition of a [pharyngeal]-type component on the entire vowel system. Like /a/, the [-ATR] vowels in Akan are also articulated with retraction of the tongue root at the pocket of the epiglottis, but they are backer than the plain low vowel /a/ in Arabic, suggesting that extra backing of the tongue root is specified.

It is not clear how many languages require low vowels and pharyngeals to be marked with the same feature. Above we suggested that low vowels in systems without pharyngeal consonants might only require the use of [+low] to distinguish them. In other languages, pharyngeal consonants exert a lowering effect on vowels, requiring the use of a common feature. In Nxaʔamxčin (Interior Salish), pharyngeal consonants cause preceding schwa and /a/ to lower, as measured by a raised F_1 (Bessell, 1991:5). A similar phenomenon occurs in Montana Salish (Flemming et al., 1994). McCarthy (1994) cites morphological examples in Arabic in which gutturals ([χ, ʁ, ħ, ʕ, ʔ, h]) induce lowering of /i,u/ to /a/. It should be noted that /a/ before a pharyngeal consonant is low but not back in Arabic. As there is an interaction between vowels and pharyngeal consonants in these languages, the low vowels would be marked as Pharyngeal. Use of

[rad] or [lpx] will be reserved for more extreme constrictions in the pharynx; [rad] for [-ATR] vowels in Akan and pharyngealized vowels in !Xóõ, and [lpx] for pharyngeal consonants and strident vowels in !Xóõ. In !Xóõ, the non-pharyngealized low vowels would simply be marked Pharyngeal. As there is a three-way contrast in !Xóõ, this is an additional argument for positing that, in general, the low vowel [a] is not underlyingly [+rad] or [+lpx].

We also need a way to describe associated movement of the larynx and pharyngeal wall. Lindau's feature [Expanded] does this, although it is linked with movement of the tongue root. In our analyses we have seen several options which do not merely reflect a set of nested, intermediate positions between [+Expanded] and [-Expanded]. Ndut displays more constriction of the pharyngeal wall than Akan and less movement of the larynx, while /q, $t^ʕ$, $s^ʕ$/ in Arabic have raising of the larynx but widening of the pharyngeal wall. If we examine movements of the larynx and pharyngeal wall separately, we find that all of the logical combinations are found: the larynx may be raised or lowered and the pharyngeal wall may be widened or constricted. Raised and widened are found together in the Larynx Raising Factor (P2) and the Pharynx Shifting Factor (P5), as is the obverse combination, lowered and constricted. The [±Expanded]-type movement, which can be broken down into raised + constricted or lowered + widened, is found in the Pharynx Expansion Factor (P4). For the languages discussed in this dissertation, excluding Akan and possibly Ndut, these categories do not appear to be used distinctively, but are rather necessary for the complete phonetic description of a segment. As movement of the pharyngeal wall and larynx appear to be distinctive only in Akan and Ndut, and the [-ATR] vowels of these languages can be distinguished from other pharyngeal segments in terms of constriction location, we will use Pharyngeal-

[radical] to represent [-ATR] vowels. However, a full articulatory description of these vowels would require description of the movement of the pharyngeal wall and larynx.

It is possible that the [lpx] feature should be defined not merely in terms of place, but as a feature which presides over various phonetic categories which affect the shape of the laryngopharynx. Some possibilities would be {larynx raising}, {pharyngeal wall constriction} and {tongue root constriction}. [lpx] would thus be a feature involving a number of phonetic dimensions. An additional role of [lpx] might consequently be as a helping feature, i.e., one that makes a contrast more salient. For instance, in those [ATR] contrasts that involve larynx height, we could hypothesize that they invoke the feature [lpx]{larynx raising} in addition to the main place feature of Pharyngeal-[rad].

There is another possibility that should be considered. Maddieson (p.c., 1998) has suggested that the results fit into " a two-place system, with also a sort of tongue-profile distinction between a more focal constriction and a longer one involving a constriction along much of the pharynx. This would be similar to the place/profile distinction among coronal consonants where one has dental, alveolar and post-alveolar place, and laminal vs. apical tongue shapes. Long laminal constrictions often spread over more than one of the locations which might be distinguished by focal (apical) constrictions...It would be quite reasonable to postulate a tongue root profile sub-node in a feature tree, with values like [flat]/[focal]." Among the cross-language partitioned factors, we might classify the Upper Pharyngeal Constriction Factor (8-16) and the Laryngopharyngeal Constriction Factor (8-17) as extended constrictions in the upper and lower pharyngeal areas, respectively, and the Dorsal Constriction Factor (8-19) and the Radical Constriction Factor (8-18) as focal constrictions at those two places. This proposal would eliminate the need for three places of articulation within the pharynx by transferring a difference in place to one of manner. In the pharynx, the problem would be deciding how long a constriction must be to count as extended. This is apparent when we consider factors from the individual language analyses. The Arabic (3) and Arabic (5) analyses suggest that there are two focal constrictions in the upper pharynx, one for uvular /q/ and one for the emphatic coronals. Ndut/!Xóõ Factor 2 shows a more extended constriction than the extended Laryngopharyngeal Constriction Factor. Akan Factor 2 is more extended than the focal Radical Constriction Factor, both of which model [-ATR] vowels. A second difficulty would be in demonstrating that a tongue profile or even a tongue root profile is active in the phonology of any of these languages. In !Xóõ, the pharyngealized and strident vowels do not act together as separate natural class and thus do not support a single tongue root node. Rather, they seem to be part of a set of back vowels, together with plain back vowels.

Above we have proposed a tripartite division of the pharynx to represent articulatory differences and phonological categories. In comparison, Ladefoged & Maddieson (1996) provide for two places of articulation in the pharynx while Halle (1989), Keyser & Stevens (1994) and McCarthy (1994) only provide one place. The two places provided by Ladefoged & Maddieson allow them to distinguish two sets of pharyngeal fricatives in the Burkikhan dialect of Agul. However, Ladefoged & Maddieson only posit one parameter for vowel (tongue root) with two explicit categories, [+ATR] and [-ATR]/pharyngealized (1996:372) (although in discussion [-ATR] vowels and pharyngealized vowels are considered distinct (Ibid.:306). While they regard !Xóõ strident vowels as distinct from the category [-ATR] and recognize that the three-way contrast in !Xóõ between plain, pharyngealized and strident vowels cannot be reduced to a single binary contrast, they do not propose an alternative feature with which to characterize the strident vowels. However, their category [-ATR] /pharyngealized could be augmented by some other feature, such as [breathy] (cf. Traill, 1985) or a "tongue root profile subnode with values like [flat]/[focal]" as suggested by Maddieson (p.c., 1998) in order to phonologically classify the strident vowels with are articulatorily so different form the pharyngealized vowels. As suggested above, one difficulty with a tongue root profile node is showing that it is active in some way in the phonology.

Ladefoged & Maddieson propose separate features for consonants and vowels, but in the following section we will show it is possible to use at least the same set of pharyngeal features for both. The tripartite place of articulation division is simpler than the addition of a manner feature of a phonation feature to handle contrasts in !Xóõ and has the advantage of a more direct articulatory basis.

Below we will look at how the features proposed above work in the phonologies of Arabic, Akan and !Xóõ.

8.3.1 Arabic

In Arabic, we need to be able to describe two phenomena: emphasis spreading and guttural lowering. The primary emphatic segments are the emphatic alveolars or coronals, [tˤ, sˤ, dˤ or ðˤ], and additionally in some dialects such as Egyptian, [zˤ]. In the PARAFAC analyses in this dissertation, the two most wide-spread segments, [tˤ, sˤ], were selected for study. We have shown the articulation to be made in the upper pharynx below the uvula for speakers of Tunisian, Iraqi and Qatari Arabic, while the constriction was shown to be closer to the epiglottis in the data set of five-speakers, which included two Syrian speakers. These emphatic consonants affect neighboring vowels and consonants, so we need to be able to describe the contrastive consonant articulation in a way which can be carried over to describe non-contrastive spreading (whether phonological or phonetic) as well.

With respect to guttural lowering, McCarthy (1994) has presented evidence from Arabic which shows that guttural consonants ([χ, ʁ, ħ, ʕ, h, ʔ] but not [q]) have an affinity for low vowels and may induce lowering or block raising of contiguous vowel segments. One example occurs in the alternation of the last vowel in the stems of perfect and imperfect verbs. Almost all of the verbs which have the vowel /a/ in both verb classes have a guttural ([χ, ʁ, ħ, ʕ, h, ʔ]) adjacent to the last vowel of the stem. It should be noted that there are exceptions in the behavior of these segments as a class. For instance, exceptions in the a/a perfect/imperfect ablaut class largely involve uvulars. Similar but slightly different phenomena are found in Tiberian Hebrew and Tigre, two other Semitic languages.[4]

McCarthy (1994) uses his proposed [pharyngeal] class in both kinds of rules, i.e. vowel lowering and emphasis spreading. One problem with doing so is apparent when we consider the reflexes of /a/. Adjacent to pharyngeal segments [ʕ, ħ] (and [ʔ, h]), /a/ is realized as either front (e.g. [æ]) or central (e.g. [a]); only in a word with emphatic consonants does it become backed ([ɑ]). The spread of [pharyngeal] has two very different effects; in one instance it defines a vowel as a low vowel but not a back one, and in another, it causes backing in the pharynx. The two effects are separable only by reference to whether the trigger consonant has one association line or two: [pharyngeal], or [pharyngeal] + [dorsal] (in McCarthy's analysis[5]). The rule would state that [pharyngeal] is spreading but in actuality something different is spreading: [pharyngeal] with respect to a [dorsal] consonant. One could also suggest that /a/ is underlyingly

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[4]In Tiberian Hebrew, laryngeals patterns with pharyngeals. In Tigre, emphatics pattern with pharyngeals in conditioning the appearance of /a/, while uvulars do not. For this reason, uvulars would not form part of a class of "gutturals" in Tigre, but it is not known if they are produced in a different way from Arabic uvulars.

[5]McCarthy (1994:220) includes emphatic coronals and all uvular consonants in the class of emphatics triggering emphasis spread. The coronal emphatics obtain the specification [dorsal] by default in relatively late rules. The class of emphatics is defined by the dual specification [pharyngeal] and [dorsal] in his analysis.

back, and fronted in other cases, but this seems counter to the rest of the phonology. A further difficulty is presented by data in Card (1983) on Palestinian Arabic, where even pharyngeal consonants are affected in words containing an emphatic consonant (as shown by lowered second formants); this would require spreading [pharyngeal] to a segment already marked [pharyngeal] (which should also block harmony across it). The same situation could occur if /a/ is marked [pharyngeal] through guttural lowering and emphasis is then spread from an affix. Normally spreading only takes place to elements without an association to the class of features being spread, so this would require that [pharyngeal] spread from a [dorsal]+[pharyngeal] consonant delink existing specifications of [pharyngeal]. It would either be the case that a very special status is accorded to segments marked as [dorsal]+[pharyngeal], or the data would seem to suggest that a different feature is involved.

In terms of both articulatory and acoustic correlates, emphasis spread seems to take place in (what was traditionally) a [back] domain, while guttural lowering takes place in a [low] domain. But using the traditional terms [back] and [low] causes several problems: 1) As pointed out by Hyman (1975:50), if one follows SPE in marking pharyngealized consonants and vowels [+back, +low] then [iˤ] cannot be distinguished from [a] nor [a] from [aˤ], and 2) how does one get the uvular [χ, ʁ], by any account [-low], to pattern with pharyngeal and laryngeal consonants in guttural lowering?

Our solution is to propose a branching node of [upper pharynx] and [laryngopharynx] under Pharyngeal, similar to what has been proposed by Czaykowska-Higgins (1987) for other reasons. Czaykowska-Higgins assumes in her proposal that the pharyngeal components of Arabic emphatic consonants are articulated by the tongue root, whereas in this proposal they would be articulated by the rear dorsum of the tongue in the upper pharyngeal airspace. [Upper pharynx] would correspond to some of the functions of [back] and [laryngopharynx] would correspond to some of the functions of [low].

Emphatic coronals will have the dual specifications [coronal] and Pharyngeal-[upper pharynx]. (We are following Ghazeli but not McCarthy in limiting the class of emphatics to coronal [tˤ, sˤ, dˤ/ðˤ, zˤ].) The specification Pharyngeal-[upper pharynx] will spread to other coronals within a word. We will assume for the moment that emphasis spreading to vowels within an affected word can best be represented by phonetic computation rules, as PARAFAC analyses of these vowels show that they do not quite attain the backing found in emphatic coronals. We do not have articulatory data on pharyngeal consonants in an emphatic domain, nor is it certain whether changes in their vocal tract shape should best be ascribed to the phonological stratum or to the level of phonetic computational rules. If further research shows emphasis spreading to pharyngeals is best represented by feature spreading (as opposed to phonetic computation rules), we would propose the spreading of [upper pharynx] to a segment marked Pharyngeal-[laryngopharynx].

Guttural Lowering is more difficult to formulate because of the need to exclude /q/ and include [ʔ, h]. We did not have sufficient x-ray data on /ʁ, χ/ to include them in the preceding PARAFAC analyses and to see if they are articulated in the same way as /q/. We propose that uvulars in Arabic have the specification Dorsal + Pharyngeal-[upper pharynx], while the pharyngeals have the specification Pharyngeal-[laryngopharynx]. As in McCarthy's analysis, Pharyngeal spreads from the guttural to the thematic vowel, but this is distinct from Pharyngeal-[upper pharynx] spread in emphatic domains. A [pharyngeal] specification without further specification would yield a segment articulated in between Pharyngeal-[upper pharynx] and Pharyngeal-[laryngopharynx], giving us an articulation at the epiglottis. This agrees with the PARAFAC results. This study did not research the means by which /q/ would be excluded from the class of gutturals. One possibility is that /q/ is a purely uvular constriction while /ʁ, χ/ are not; /ʁ, χ/ are represented by Pharyngeal-[upper pharynx] whereas /q/ is not.[6] This is pure speculation and would require further research.

Another difficulty is that the laryngeals are also included with the pharyngeals in the class of gutturals. McCarthy (1994) places the laryngeal segments [h, ʔ] under the [pharyngeal] node. However, it is not clear that a place of articulation is necessary for glottal consonants in languages such as Toba Batak, and in fact, accommodating the analysis of glottal stop formation in Hayes (1986) would require that the glottal consonants only have laryngeal features. McCarthy recognizes this difficulty and suggests that there are two kinds of laryngeals: those in Arabic are specified as [pharyngeal] while others are not.

A different approach to the relation in Semitic of laryngeals to segments articulated in the pharynx is to posit the possibility of a more complex articulation of the laryngeals, involving some part of the pharynx. (McCarthy (1994) proposed that the pharynx include laryngeal articulations for some, but not all, languages.) Lindqvist (Gauffin) (1969, 1972) introduces the possibility of recognizing two different kinds of laryngeal constriction: one at the level of the vocal folds and one at the level of the aryepiglottic folds. The aryepiglottic folds (see (2-4)) extend from the sides of the epiglottis to the apexes of the arytenoid cartilages. They are also involved in gestures of protective closure, which is performed by the aryepiglottic muscles within the folds, the oblique arytenoid muscles and the thyroarytenoid muscles. Lindqvist's pictures of a phonetician's glottal stop taken

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[6]Maddieson (p.c.) has pointed out that, "Given the occurrence of languages (e.g., Tsez) in which there are contrasts between plain and pharyngealized uvulars, it is probably not workable for all uvulars to be considered +Pharyngeal (unless the pharyngealized ones are also [+lpx]...)." In Arabic, /ʁ, χ/ would need to receive a Pharyngeal specification in order to be classified as a "guttural" consonant. In other languages this would not be the case.

through a fiberoptic laryngoscope do show this second kind of closure. Given the phonological grouping of laryngeals and pharyngeals in Arabic, it is possible that the Arabic laryngeals are not purely glottal, but have aryepiglottic constriction. McCarthy (1994:225) however, after considering this possibility noted that there is no sign of any effect on the formant frequencies of vowels adjacent to Arabic laryngeals, as we might expect if they did have aryepiglottic closure. But as there has been little research done on the articulation of Arabic laryngeals, this possibility is not completely ruled out.

In summary, for Arabic we have proposed the categories Pharyngeal-[upper pharynx] to represent retraction at the uvula and just below for uvular /q/ and emphatic coronals and Pharyngeal-[laryngopharynx] for pharyngeal consonants. Low vowels would be marked as Pharyngeal to facilitate Guttural Lowering, but would not be marked for [upper pharynx] or [laryngopharynx].

8.3.2 Akan

In the preceding sections we have proposed that the Pharyngeal node, without subdivisions, be used to represent low vowels in languages such as Arabic which demonstrate connections between low vowels and pharyngeal consonants. PARAFAC analyses of low vowels in Arabic show that they are similar in constriction location but not as backed as the low [-ATR] vowel in Akan: [-ATR] involves a backer constriction centered on the pocket of the epiglottis than does the plain Arabic low vowel. The [ATR] vowel system of languages such as Akan requires the further superimposition of a [pharyngeal]-type component on the entire vowel system. The constriction location of [-ATR] vowels is different from that of pharyngeal consonants and the strident vowels of !Xóõ, and is centered at the pocket of the epiglottis. As this constriction seems to be articulated by the tongue root, we proposed that [±ATR] vowels be distinguished by the feature specification Pharyngeal-[radical].

In both Akan and Ndut, the difference between vowel harmony sets is also associated with both larynx and pharyngeal wall movement. Movements of the larynx and pharyngeal wall are decisive in distinguishing vowels harmony sets in Akan, and these settings would need to be included in the implementation of Pharyngeal-[radical]. Alternatively, Akan and Ndut would be marked for different phonetic categories of the feature [lpx] such as {larynx raising} and {pharyngeal wall constriction}. Degree of larynx raising and pharyngeal wall movement is different in Ndut than in Akan and would require a different set of implementation rules. Ndut displays more constriction of the pharyngeal wall and less movement of the larynx than Akan, and in fact more movement of the pharyngeal wall than movement of the tongue root. This difference would be difficult to capture by Lindau's [Expanded], as the option of more pharyngeal wall movement and less tongue root movement was not originally envisaged. For the other languages discussed in this dissertation, excluding Akan and Ndut, movement of the larynx and pharyngeal wall does not appear to be used distinctively, but specification of these movements is necessary for the complete phonetic description of a segment.

8.3.3 !Xóõ

In !Xóõ, the main phonological tasks are to describe the inventory of segments and their distribution. In this study, we wish to describe the articulatory and phonological differences between three types of low vowels: plain, pharyngealized and strident. Tracings of each are shown in (1-4). From the tracings, it appears that the plain and pharyngealized vowels do not differ so much in location of constriction as in degree of constriction. The pharyngealized /a/ is pressed back almost to the pharyngeal wall, but in roughly the same location as the plain /a/. However the strident /a/ has a deeper constriction location closer to the larynx. There are thus three types of vowels with a constriction at the epiglottis or lower. If we try to utilize the same categories as in Arabic, plain /a/ would be identified with Pharyngeal and the strident /a/ would be identified as Pharyngeal-[laryngopharynx], particularly as the strident vowels appear to use the same partitioned factor, the Laryngopharyngeal Constriction Factor (T2), as pharyngeal consonants. For pharyngealized vowels we propose attaching [radical] directly to Pharyngeal to indicate a more extreme articulation than plain low vowels. The category Pharyngeal-[upper pharynx] would also be used in !Xóõ for uvular /q/.

There are no segmental phonological rules involving these segments, so we will examine their distribution. There are separate constraints for vowels of the first mora and vowels of the second mora of a word. Vowels of the first mora of a !Xóõ word can be breathy-voiced, glottalized, pharyngealized, or any combination of the three, but only back vowels can be pharyngealized. Vowels of the second mora can be nasalized, in which case nasalization spreads to the vowel of the first mora. (Also indicative of the different status of vowels in the first and second morae: if the low vowel /a/ occurs in the first mora, it can be raised by dental consonants or the vowel /i/, but this is blocked if the vowel in the second mora is /a/.) A table of possibilities is given in (8-23), with examples of the vowel /a/, from Traill 1981:68 (using Traill's orthographic system). (8-24) shows how the same table would look with the inclusion of the features Pharyngeal-[rad] and Pharyngeal-[lpx]:

(8-23) Features for !Xóõ vowels from Traill (1985)

		nasalized*	breathy	pharyn-gealized	breathy + nasalized *
plain	sâa				
nasalized*	qāã				
breathy	qâha	?Θàhã			
pharyngealized†	qa̰a	ta̰ã	?ā̰hna Δ		dzā̰hĩ Δ
glottalized	dtsxâ?a	sà?ã	gáh?n †	!nâ̰?m †	àh?ã †

Notes:

Tones: ´ =high ˉ = mid-level ˆ=mid-falling ˋ=low

*Nasalization is spread from the vowel of the second mora to the vowel of the first.

ΔThese contain a strident vowel. †No attested examples of front vowels.

(8-24) Revised features for !Xóõ vowels

		nasalized*	breathy	pharyn-gealized	breathy + nasalized *
plain	sâa				
nasalized*	qāã				
breathy	qâha	?Θàhã			
Pharyngeal-[rad]	qa̰a †	ta̰ã †			
Pharyngeal-[lpx]	?ā̰hna Δ†	dzā̰hĩ Δ†			
glottalized	dtsxâ?a	sà?ã	gáh?n †	!nâ̰?m †	àh?ã †

Notes:

Tones: ´ =high ˉ = mid-level ˆ=mid-falling ˋ=low

*Nasalization is spread from the vowel of the second mora to the vowel of the first.

ΔThese contain a strident vowel. †No attested examples of front vowels.

One of the reasons Traill analyzes the strident vowels (see Δ in (8-23) and (8-24) above) as pharyngealized + breathy is that breathy-voicing occurs with glottalized vowels but would not otherwise occur with pharyngealized vowels. Reanalyzing the strident vowels in terms of location of constriction (8-24) leads to a slightly less neat phonological paradigm but a more straightforward phonetically-based paradigm. The glottalized series in (8-24) remains asymmetrical. However, the articulation of pharyngealized and strident (pharyngealized + breathy) vowels is rather different and is not obviously the superimposition of breathiness on pharyngealization. The strident vowels are articulated with a much lower tongue position and with the cushion of the epiglottis retracted against the tips of the arytenoid cartilages. This is reflected in the use of the Laryngopharyngeal Constriction Factor (T2) by Xóõ speakers.

Plain /a/, pharyngealized /a/ and strident /a/ in !Xóõ can all be distinguished by tongue position without reference to voice quality. Inspection of Xóõ x-ray tracings (see (1-4)) shows that the plain /a/ and the pharyngealized /a/ are both articulated at the pocket of the epiglottis with the latter more retracted than the former, while the strident /a/ is articulated in the laryngopharynx.

8.3.4 Summary

We have seen that Arabic requires a division of the pharynx in two to account for the separate patterning of emphatic consonants and pharyngeal consonants. Our analyses have shown that the emphatic consonants have a constriction in the upper pharynx while the pharyngeal consonants have a constriction in the laryngopharynx. Accordingly we have proposed the categories [upper pharynx] and [laryngopharynx]. Our analyses found a different constriction location for [-ATR] vowels, at the pocket of the epiglottis, for which we have proposed the category Pharyngeal-[radical]. We must also capture the fact that pharyngeal consonants have an affinity for low vowels (which are however not backed) despite articulatory evidence here showing a more constricted laryngopharynx for pharyngeal consonants than for low vowels. For this we propose using the term 'Pharyngeal', without modification, for plain low vowels. The harmony feature found in Ndut and Akan affects only vowels, consonants are transparent, and low vowels tend to be [-ATR]. Neither Akan nor Ndut has any consonants articulated in the pharynx which could block the spread of a pharyngeally-defined feature. In Xóõ, we have proposed that the phonological difference between pharyngealized and strident vowels be represented by the categories Pharyngeal-[radical] and Pharyngeal-[laryngopharynx].

8.4 Residual issues

One of the most intractable problems is the assignment of features to low vowels and pharyngeal consonants. Vowels require a set of features for height and backness, each expressed in a single dimension in order to easily express rules for fronting/backing or raising/lowering, while consonants are in general more usefully described in terms of place of articulation. There still needs to be a common set of features between consonants and vowels to express assimilation rules such as palatalization or guttural lowering. It has been argued that it is preferential not to have duplicate features, for example [+low, +back] and [-ATR], which both express retraction of the tongue root. But [-ATR] expresses a unitary phenomenon which otherwise takes two features to express, and [+low] is useful in assigning [-ATR] to low vowels in Akan and Ndut. But should [+low] be assigned to the Dorsal articulator, as is done in most articulator-based theories, or to whatever category characterizes the tongue root? If [+low] is assigned to the tongue root and [+high] assigned to the dorsum it makes expression of height changes very cumbersome, as any shift from high to low or low to high involves a change between articulators. Lahiri & Evers (1991) partially resolve this problem by proposing a Tongue Height Node separate from other branches of the Place Node. This allows height changes only within vowels to be represented easily, but leaves the same redundancies in that some consonant features also represent height differences. In this dissertation we have chosen to represent low vowels with the unmodified node Pharyngeal to facilitate expression of rules involving low vowels and pharyngeal consonants.

There is also a striking vocal tract shape associated with many pharyngeal articulations but not picked up by the PARAFAC analyses here, in which the blade of the tongue is fronted and there is a concomitant cambering of the tongue under the soft palate and uvula. The tongue often appears stretched between two bulges: one at the front of the mouth and one in the low pharynx. Examples can be seen in (1-5) ([ħ]) and (1-11) ([aˤ]). The first example suggests that some pharyngeal consonants should be analyzed as multiple articulations with coronal and pharyngeal places of articulation. This might explain why front low vowels occur adjacent to pharyngeal consonants when we might expect a back low vowel.

It should also be stressed that there is no evidence in the data-sets used here of the epiglottis acting as an independent articulator in the sense that the epiglottis is extended away from the tongue root to create a constriction against the pharyngeal wall. In every case examined here, the epiglottis is pushed back by the tongue root and may articulate with the pharyngeal wall only if the tongue root is sufficiently retracted. (This is in agreement with phonetic evidence discussed in Chapter 2.) The only debatable example perhaps is the strident vowels of Xóõ, where it is the cushion of the epiglottis rather than the tip which constricts the laryngopharynx.

We have left open the question whether the upper pharynx requires further subdivision. While we found different constriction locations in the upper pharynx for uvular /q/ and emphatic coronals in Arabic we have chosen to allow that difference to be represented by the links to other articulators; [coronal] for the emphatic coronals and [dorsal] for the uvular stop in addition to Pharyngeal-[upper pharynx] for both.

There is still much to be learned about pharyngeal articulations. We were not able to include x-ray data on Caucasian languages because of the uneven quality of the tracings, and more articulatory data is needed to determine how many contrasting articulations are found in the pharynx in these languages. More work needs to be done on Arabic emphasis spread to determine if it is best represented on a phonological level or as phonetic coarticulation.

8.5 Summary and Conclusions

In this dissertation we have striven to make use of existing cinefluorographic films where possible and published tracings in cases where the films themselves were not available in order to compare different articulations made in the pharyngeal airspace. Analysis through PARAFAC was used in order to obtain a better sample of tongue and vocal tract shapes and their internal dependencies. Factors modeling (some of) the articulatory dimensions of each individual language were extracted through PARAFAC analyses. A set of factors modeling the data-sets for all languages in this study was obtained, following Jackson (1988a), by analyzing covariance matrices. These factors were then compared with individual language data-sets through backward-stepping analyses in order to determine which best modeled the articulations in each language. This method allowed us to compare articulations across languages more directly. A summary of these findings is given at the beginning of this chapter.

The three most important findings are: 1) [-ATR] vowels are articulated in a different way from the emphatic vowels in Arabic. The former have a constriction at the pocket of the epiglottis while the latter display retraction of the rear dorsum in the upper pharynx. This would argue against identifying [-ATR] vowels and Arabic emphatic vowels with a common feature such as [Expanded]. 2) Emphatic coronals are not articulated in the same way as pharyngeal consonants in Arabic. The emphatic coronals show retraction above the pocket of the epiglottis while the pharyngeal consonants show constriction of the laryngopharynx. The different effects of emphatic coronals and pharyngeal consonants on adjacent vowels in Arabic derive from their different pharyngeal constrictions. Phonological representation is more straightforward if this difference in recognized in feature representations. 3) The constrictions for pharyngeal consonants and [-ATR] vowels also differ. The pharyngeal consonants involve constriction in the laryngopharynx below the pocket of the epiglottis which is different from the constriction of [-ATR] vowels along the length of the epiglottis.

We have proposed a tripartite division of the pharynx to account for the phonological and articulatory contrasts in the languages investigated in this dissertation. The Pharyngeal node will be divided into [upper pharynx], [radical], and [laryngopharynx] constriction locations. Representation of emphatic consonants (and possibly vowels) requires a representation distinct from that of pharyngeal consonants, and the term [upper pharynx] has been proposed. Pharyngeal consonants were found to have a constriction involving the laryngopharynx. [-ATR] vowels displayed a constriction centered at the pocket of the epiglottis, different from pharyngeal consonants, and we have proposed the category [radical] for [ATR] vowels to represent this difference. !Xóõ vowels show that a distinction between a [radical] place and one in the [laryngopharynx] can be found in the same language. It may be that a constriction in the laryngopharynx place implies voice-quality changes, but that is another topic for future research.

These proposals are based on the results of the PARAFAC analyses reported here as well as discussion of other data in the literature. All of the various kinds of consonant and vowel articulation listed in the introduction can be captured under this proposal. Adopting the branching categories [radical] and [laryngopharynx] allows us to represent differences between segments articulated at the pocket of the epiglottis and those articulated in the laryngopharynx.

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APPENDIX A Arabic wordlists and tracings.

I. Words from which tracings were made.

Ia. Tunisian Arabic from Ghazali (no date). Glosses from Ghazali (1977:16-18). "V1" indicates that the first vowel was traced.

segment	word	gloss
s	sæmilli	"he priced (something) for me"
sˤ	sˤimiːli	"fast for me (imperative, fem.)"
t	tæːb	"he repented"
tˤ	tˤɑːb	"it cooked"
k	kælb	"a dog"
q	qɑlbeːn	"two hearts"
ħ	ħæːli	"my condition"
ʕ	ʕæːli	"high"
i	bifiːd (V1)	"he (it) will be useful"
iˤ	biˤðˤiˤːʕ (V1)	"he is going to get lost"
æ	tæːb	"he repented"
ɑ	tɑːb	"it cooked"
u	tuːb	"repent (imperative)"
uˤ	tˤuˤːb	"bricks"

Ib. Iraqi Arabic from Ali (no date). Glosses from Ali (p.c.).

s	kasara	"he has broken"
sˤ	qɑsˤɑrɑ	"he became/bleached"
t	tabaʃir	"revelation"
tˤ	tˤɑbɑʃir	"chalk"

k	kɛlb	"a dog"
q	qɑlb	"heart"
i	fasiːl	"a small (date) palm tree"
iˤ	qɑsˤiˤr	"handicapped/bleached"
a	fasiːl	"a small (date) palm tree"
ɑ	fɑsˤiˤːl	"platoon, squadron"
uˤ	tˤuˤb	"enter (imperative)"

Ic. Damascan Arabic from Haskins (1962). Glosses from *Background Notes* supplied with the film.

Speaker 1:

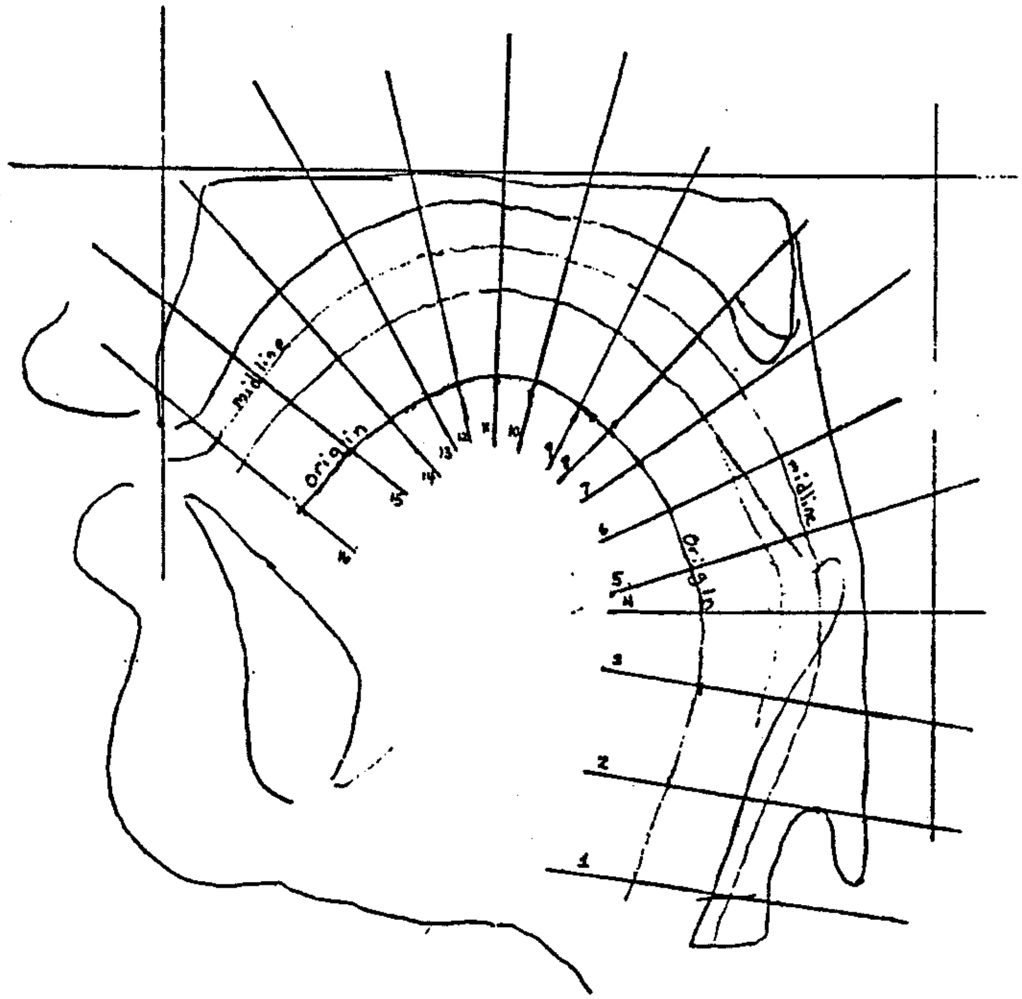
s	saff	"swallow powder"
sˤ	sˤɑff	"class"
t	teːs	"goat"
tˤ	tˤeːr	"bird"
k	keːd	"nasty trick"
ħ	ħeːz	"boundary"
ʕ	ʕɑdd	"count"
i	tiːn	"figs"
iˤ	tˤiːn	"mud"
a	taːb	"reform"
ɑ	tˤɑːb	"get well"
u	tuːl	"tulle"
uˤ	tˤuˤːl	"height"

Speaker 2:

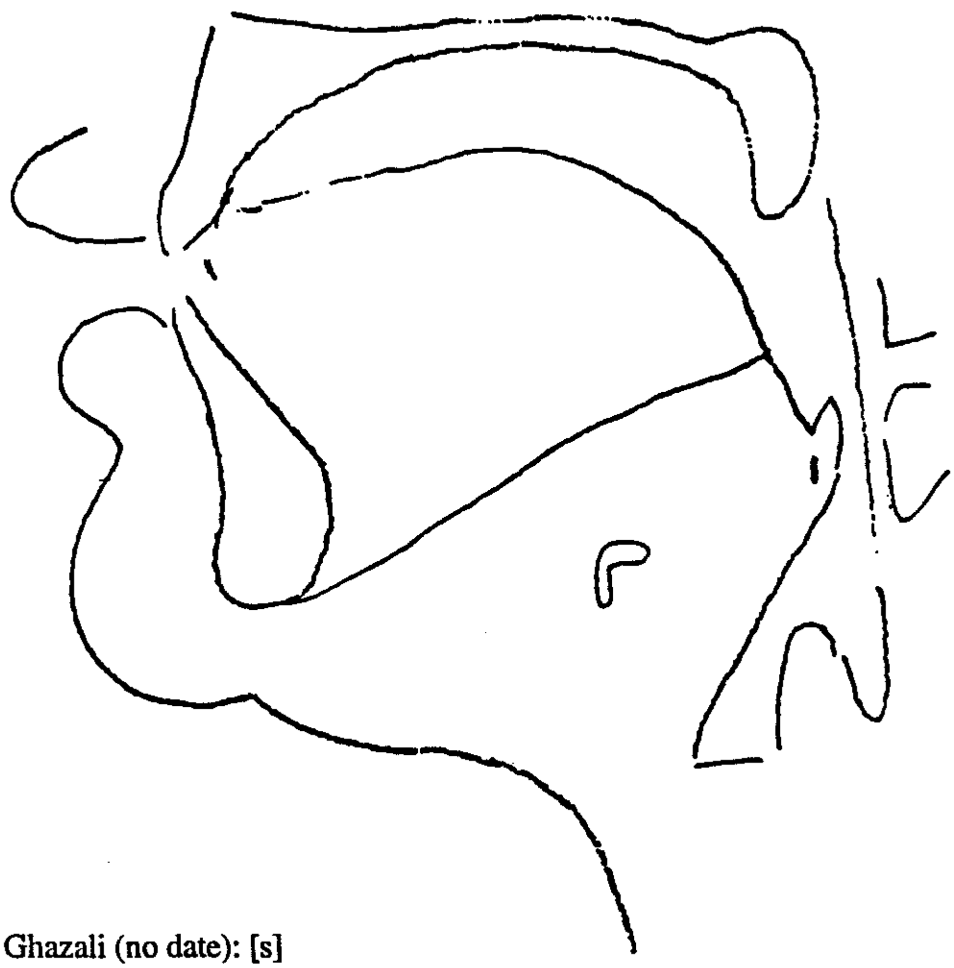
s	sɑːħ	"travel"
sˤ	sˤɑːħ	"crow"
t	teːs	"goat"
tˤ	tˤeːr	"bird"
k	keːd	"nasty trick"
ħ	ħeːz	"boundary"
i	tiːn	"figs"
iˤ	tˤiˤːn	"mud"
a	taːb	"reform"
ɑ	tˤɑːb	"get well"
u	tuːl	"tulle"
uˤ	tˤuˤːl	"height"

II. Arabic Tracings. All stops were traced one frame prior to release; all vowels were traced in a steady state portion in the middle of the vowel. Broken lines indicate projections used to formulate missing value estimates.

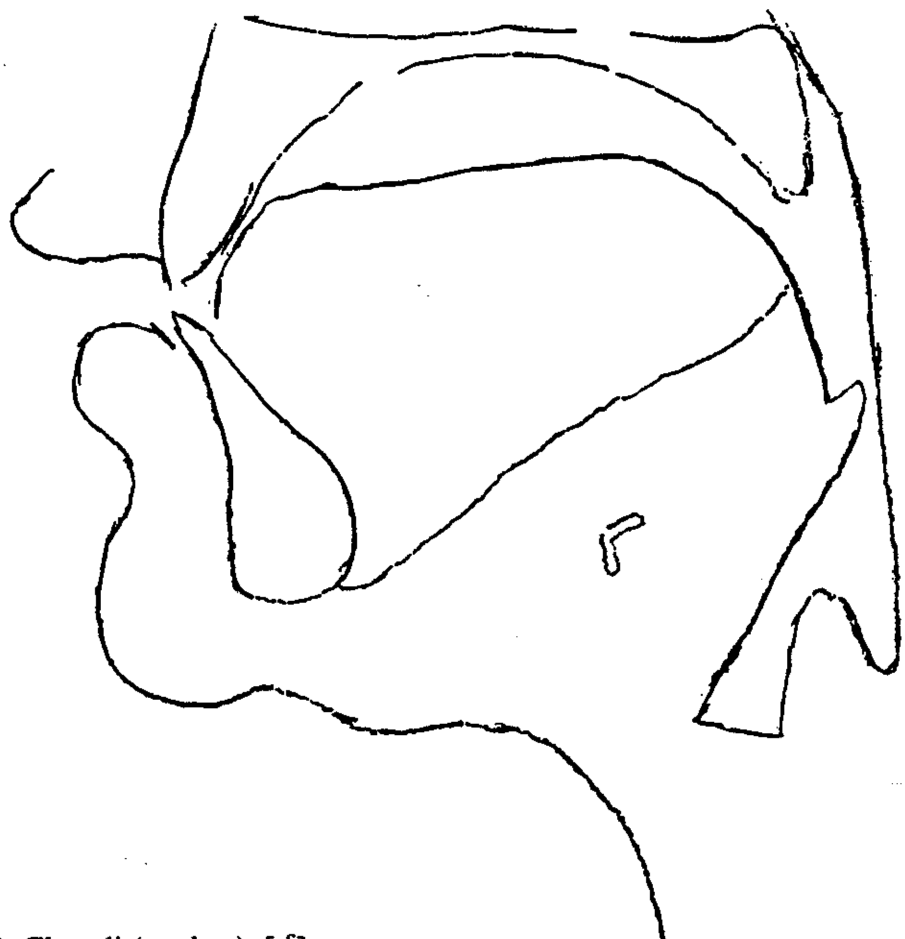
IIa. Tracings of Tunisian Arabic from Ghazali (no date).



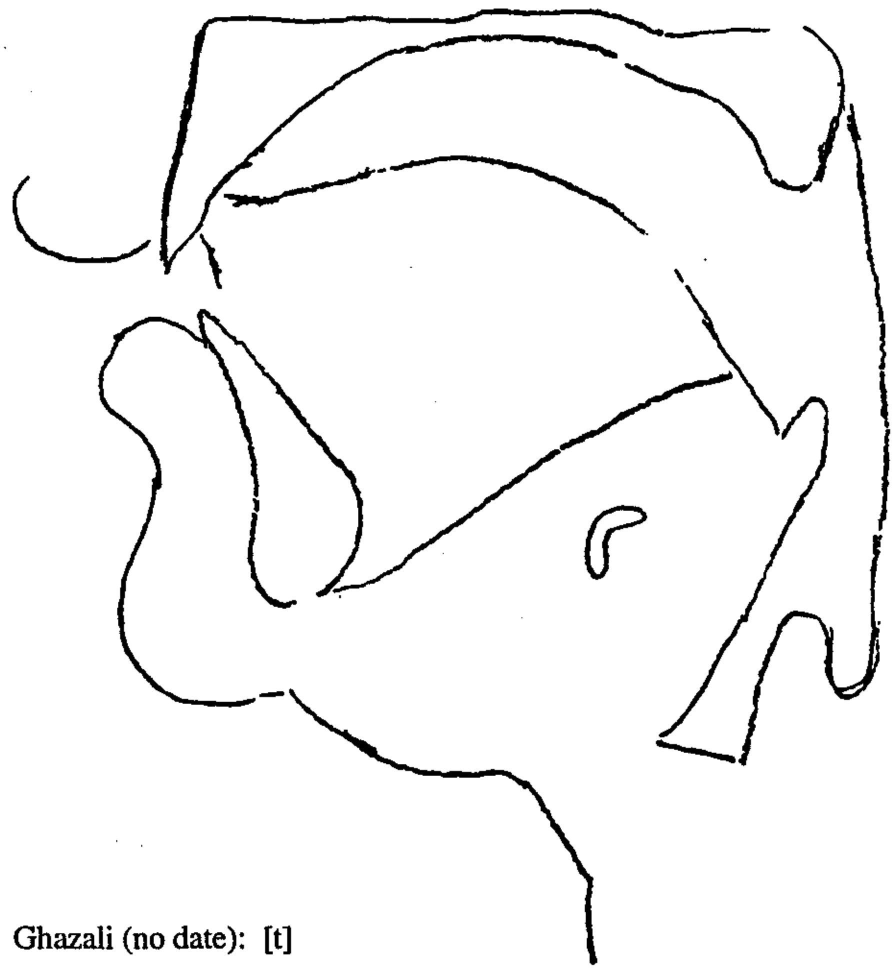
IIa.1 Measurement grid for Ghazali.



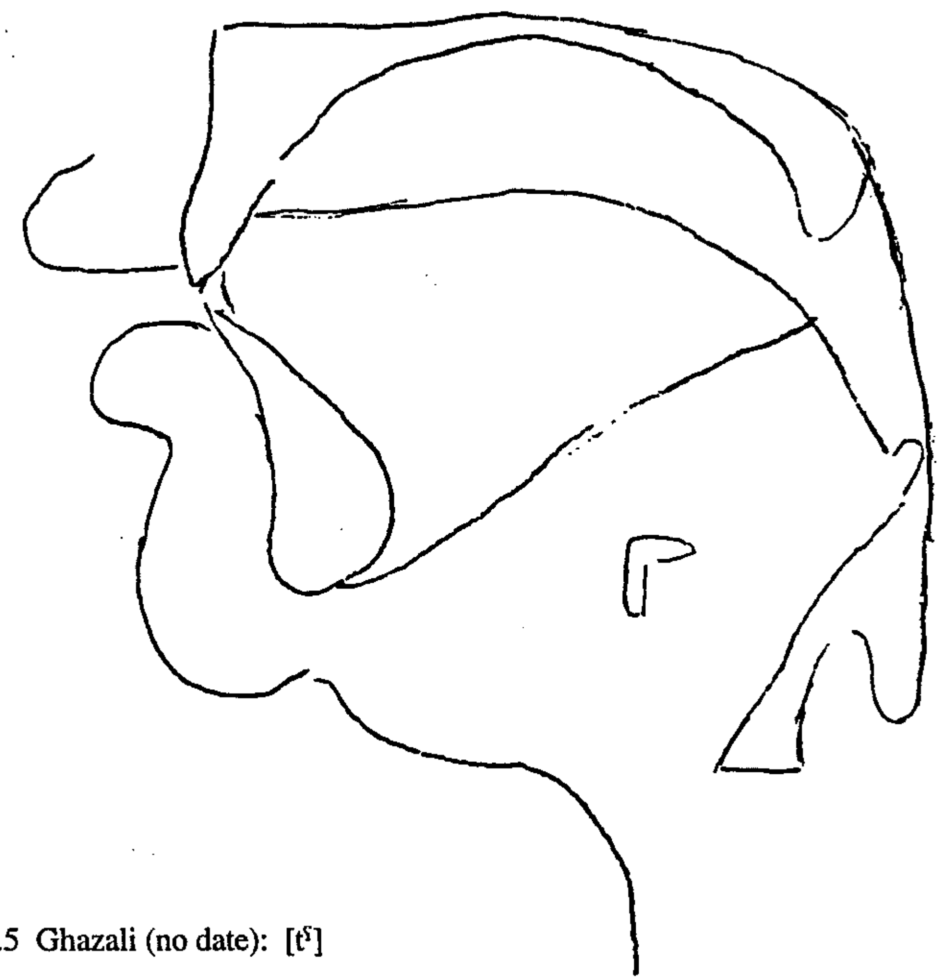
IIa.2 Ghazali (no date): [s]



IIa.3 Ghazali (no date): [$s^{\text{ʕ}}$]

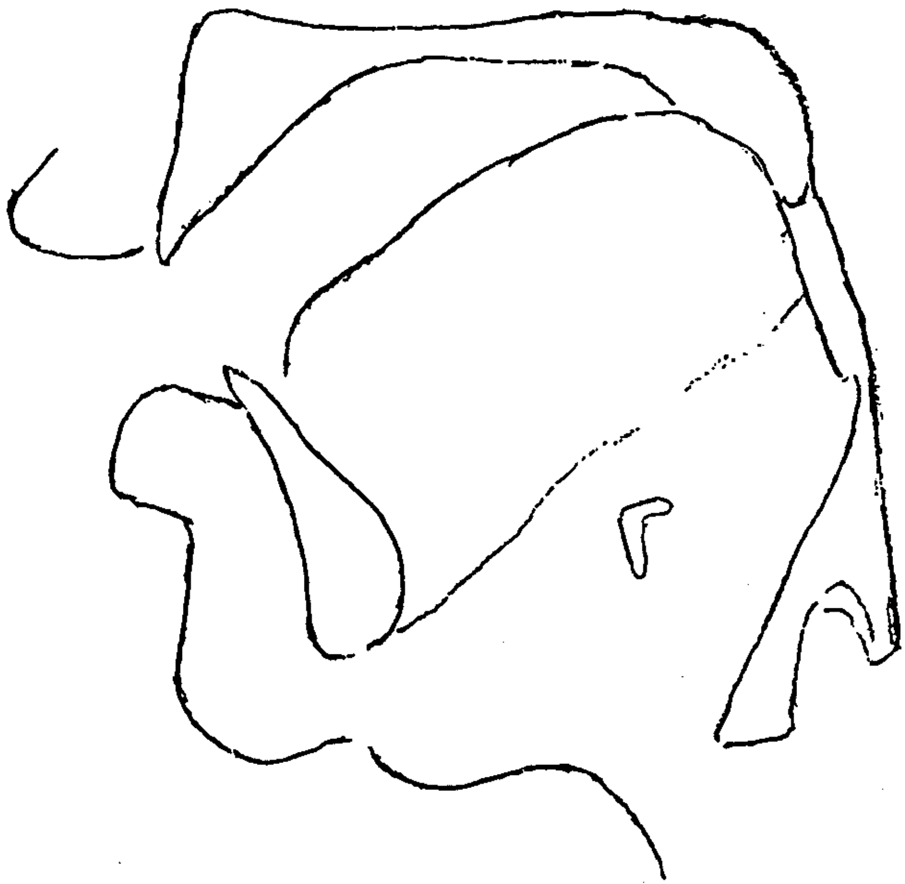


IIa.4 Ghazali (no date): [t]

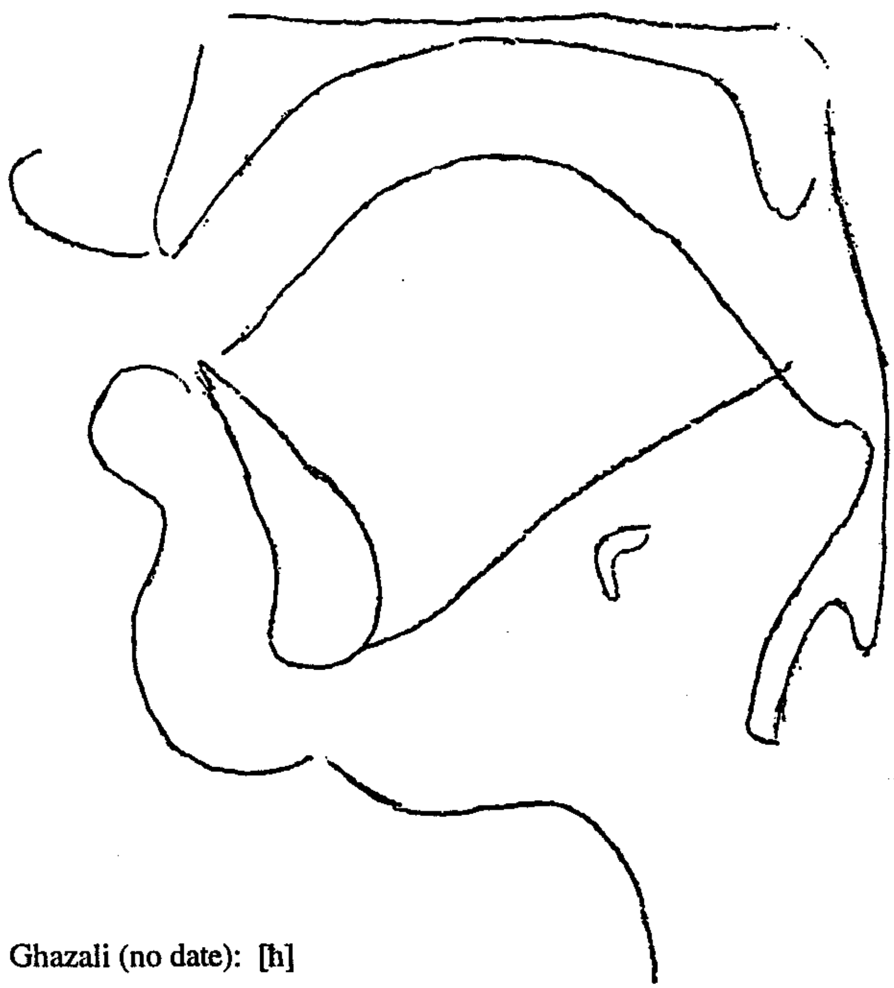


IIa.5 Ghazali (no date): [tˤ]

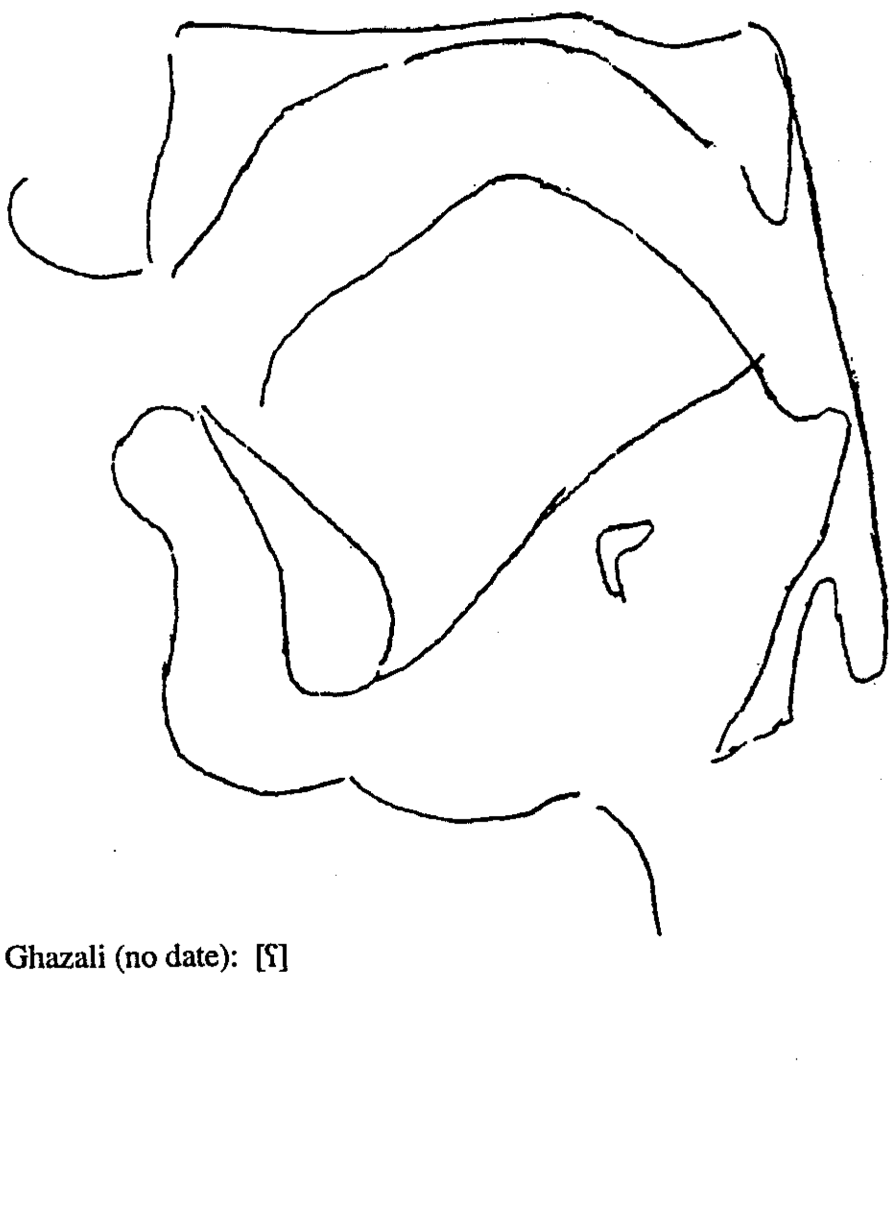
IIa.6 Ghazali (no date): [k]



IIa.7 Ghazali (no date): [q]



IIa.8 Ghazali (no date): [ħ]

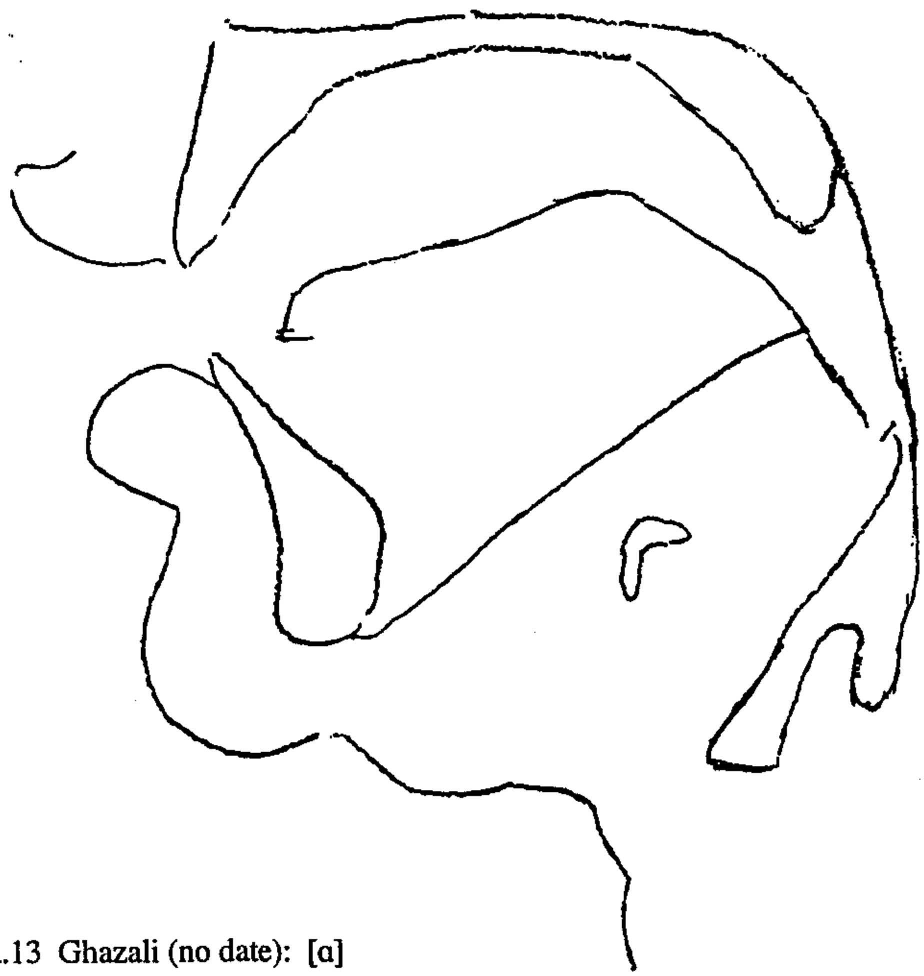


IIa.9 Ghazali (no date): [ʕ]

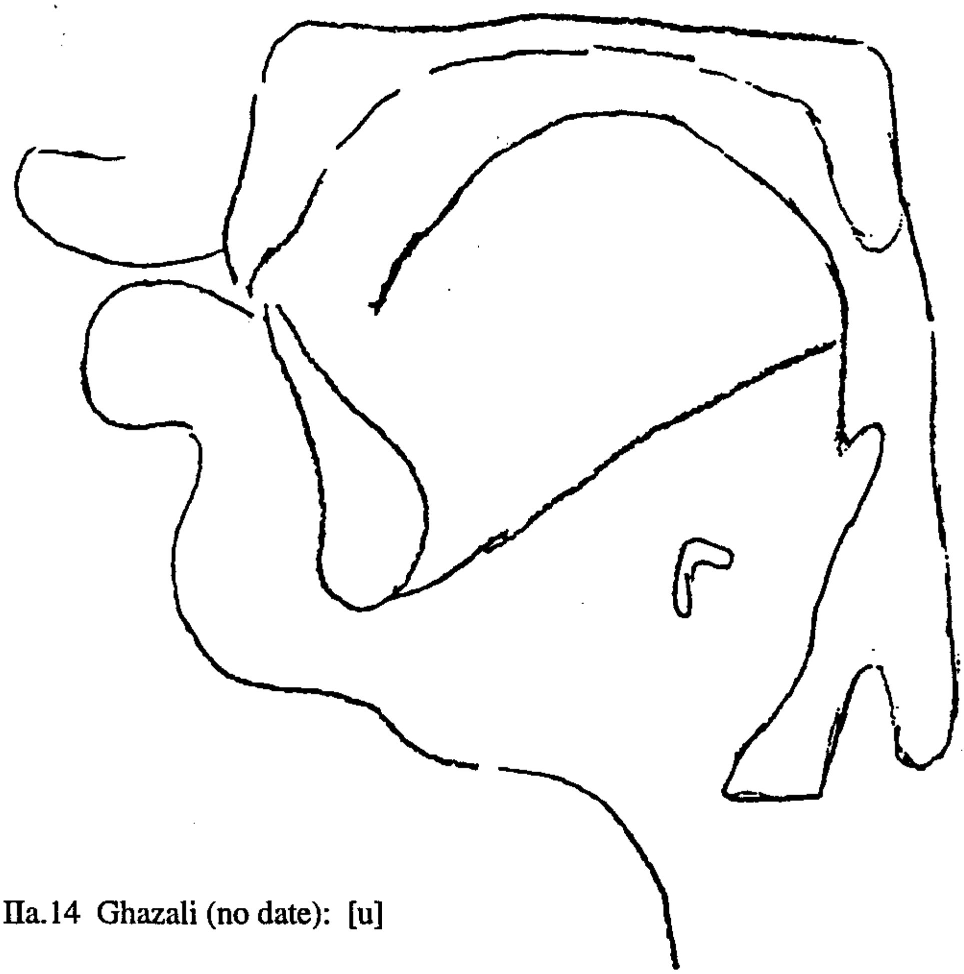
IIa.10 Ghazali (no date): [i]

IIa.11 Ghazali (no date): [iˤ]

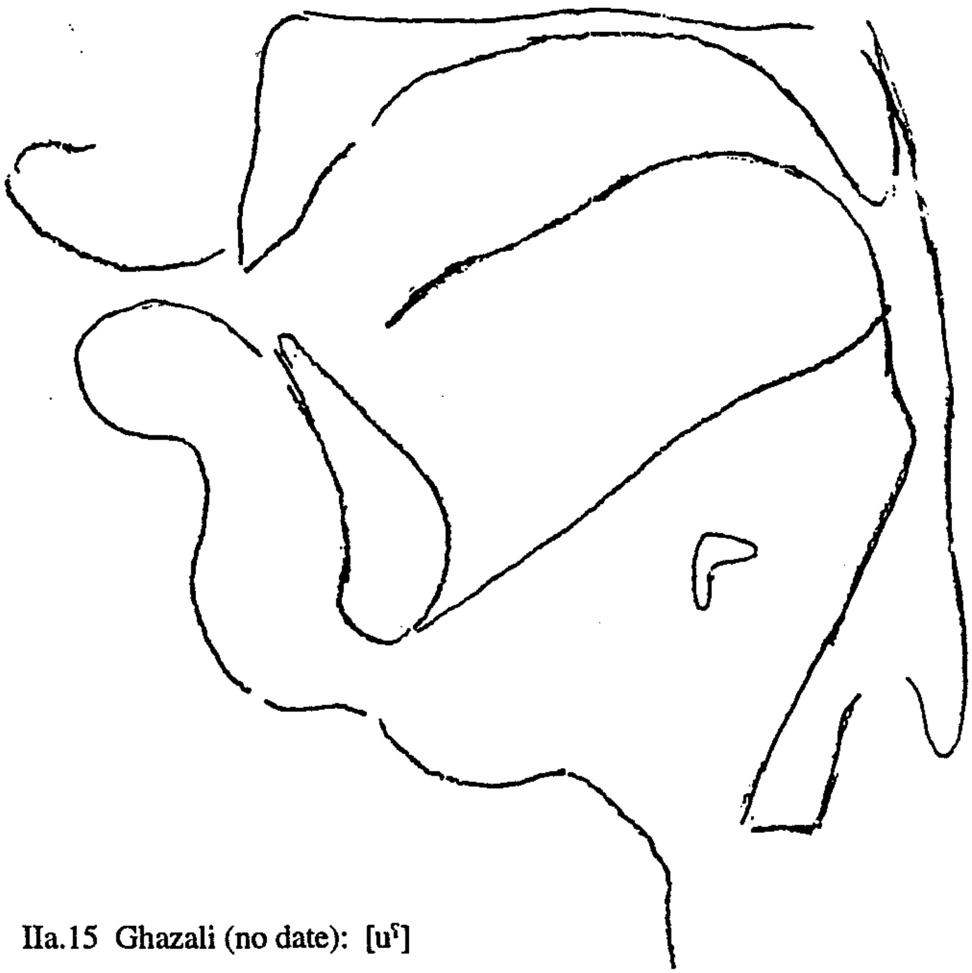
IIa.12 Ghazali (no date): [æ]



IIa.13 Ghazali (no date): [ɑ]

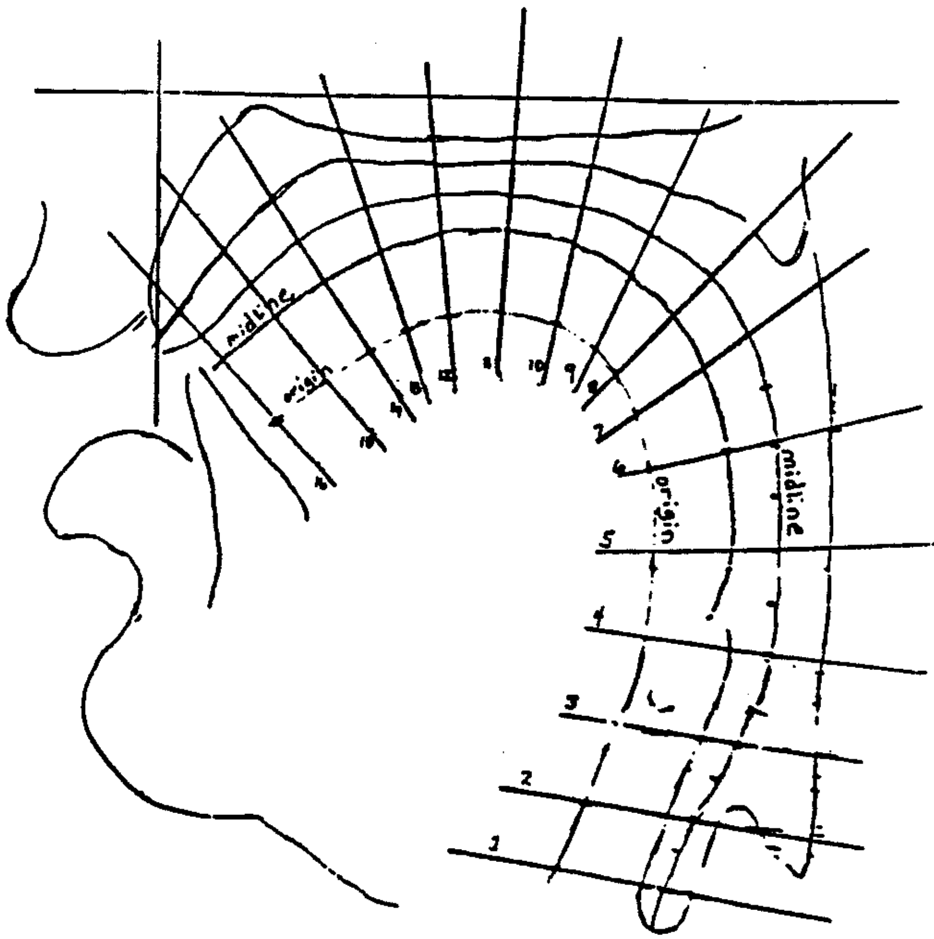


IIa.14 Ghazali (no date): [u]

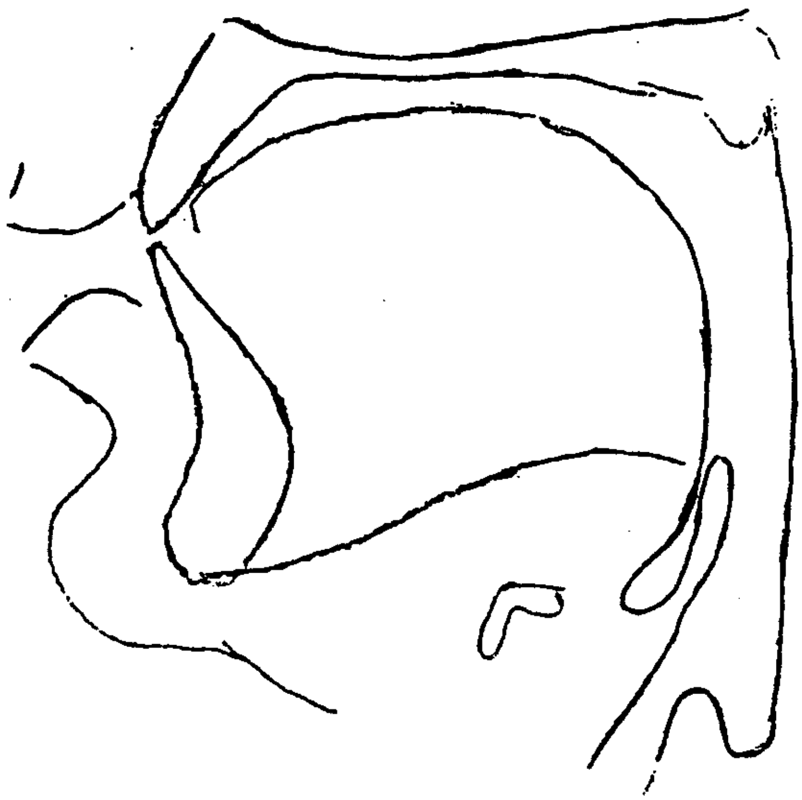


IIa.15 Ghazali (no date): [uˤ]

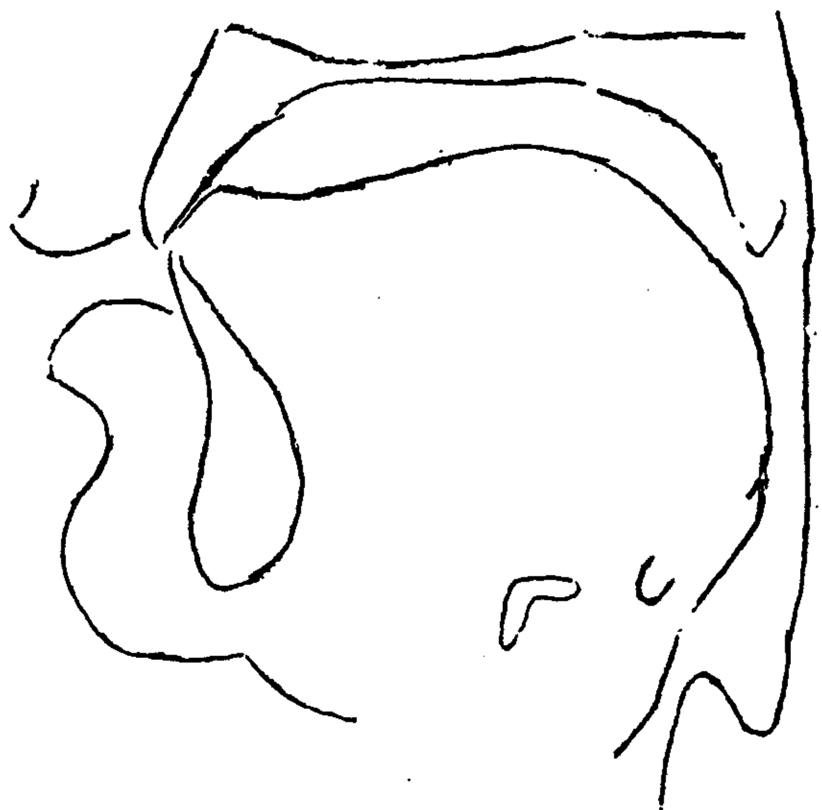
IIb. Tracings of Iraqi Arabic from Ali (no date). This film is of Ali's Speaker 2 (other films were not available).



IIb.1 Measurement grid for Ali's Speaker 2.



IIb.2 Ali (no date): [s]



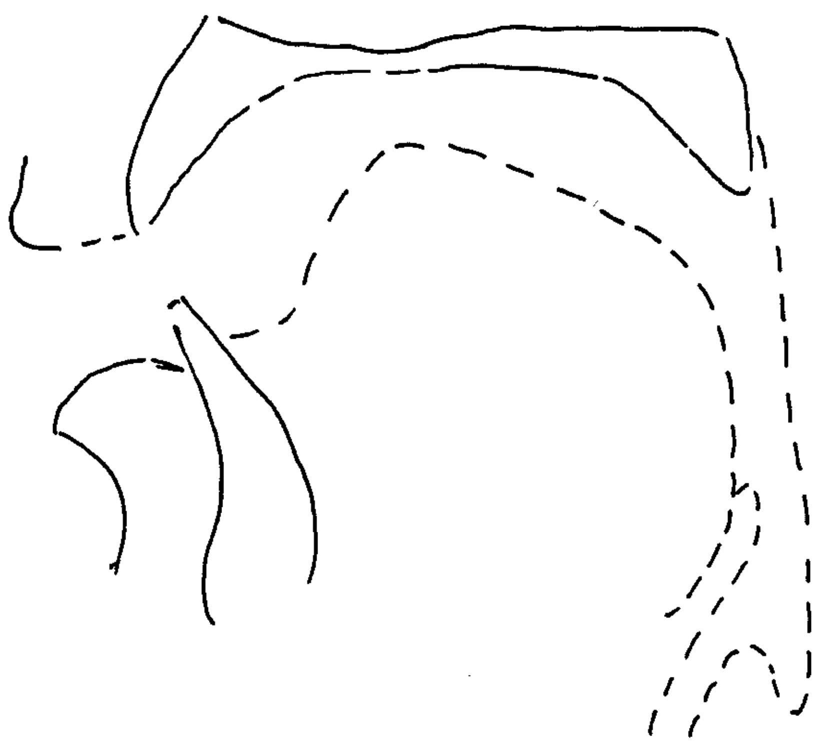
IIb.3 Ali (no date): [sˤ]

IIb.4 Ali (no date): [t]

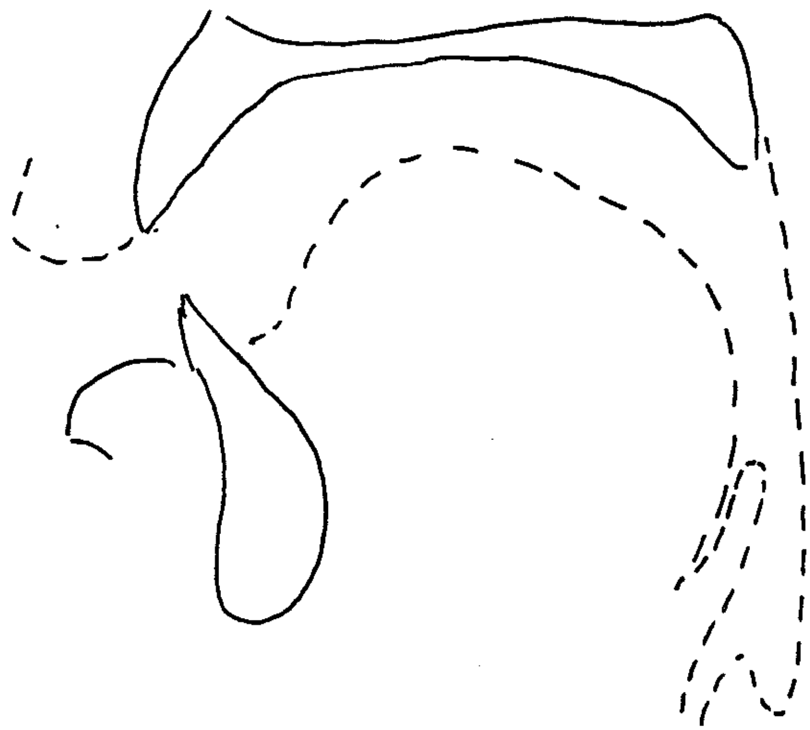
IIb.5 Ali (no date): [$t^{ʕ}$]

IIb.6 Ali (no date): [k]

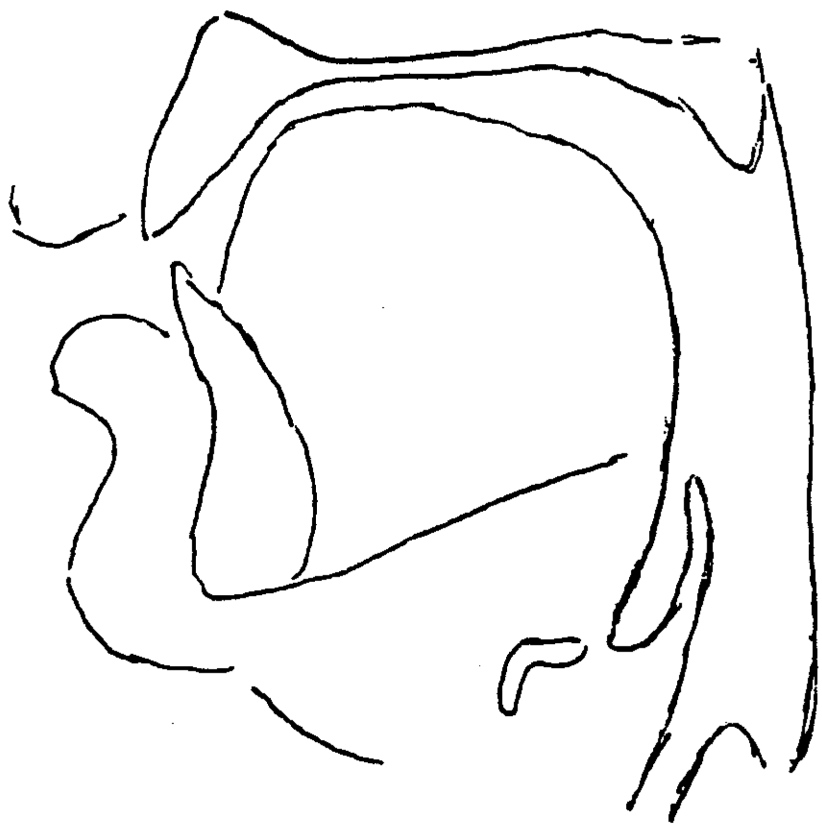
IIb.7 Ali (no date): [q]



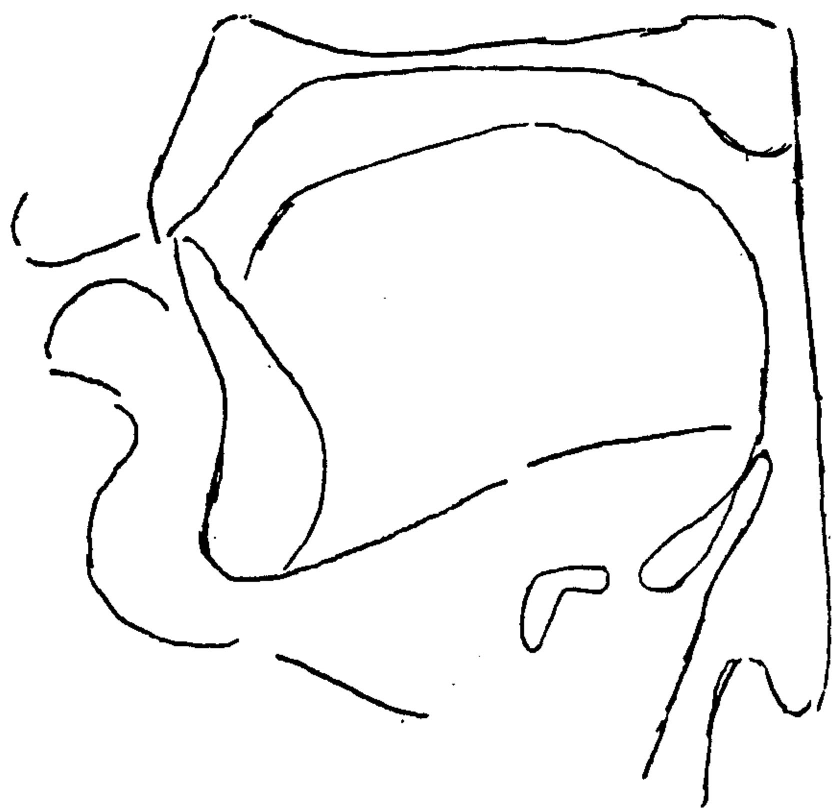
IIb.8 /ħ/: Estimated tract shape using template of Ali's Speaker 2 and tracing of Iraqi /ħ/ from Al-Ani (1970).



IIb.9 [ʕ]: Estimated tract shape using template of Ali's Speaker 2 and tracing of Iraqi [ʕ] from Al-Ani (1970).



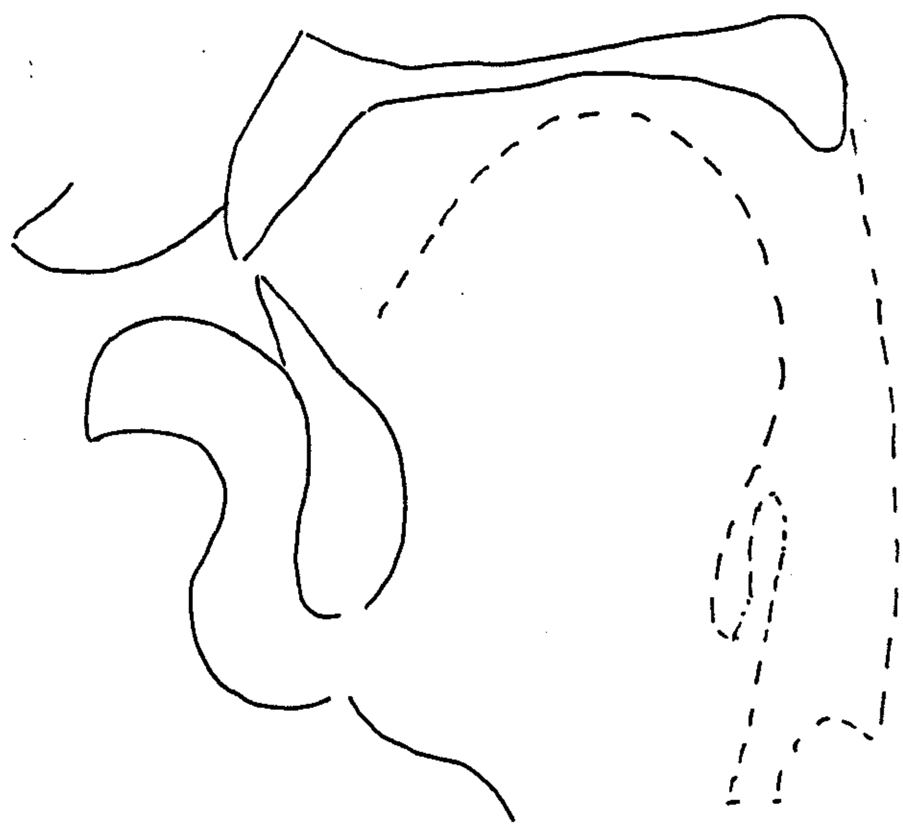
IIb.10 Ali (no date): [i]



IIb.11 Ali (no date): [iˤ]

IIb.12 Ali (no date): [a]

IIb.13 Ali (no date): [ɑ]



IIb.14 [u]: Estimated tract shape using template of Ali's Speaker 2 and tracing of Ali [uˤ] (IIb.15).

IIb.15 Ali (no date): [uˤ]

APPENDIX B !Xóõ wordlist and tracings.

Ia. Words from which tracings of Speaker G (also referred to as Speaker 1 in the text) were made. Glosses provided by Tony Traill (p.c.). * indicates Dr. Traill was unable to provide a gloss.

segment	word	gloss
i	ǁɢuˤli	genital
e	qabe	kiss her
ɑ	dt'kx'ɑlɑ	cut open
o	ǂoe	mouth
u	ǁxʊbu	*
ʊ	ǁxʊbu	*
ɑˤ	qɑˤɑ	long ago
uˤ	ǁɢuˤlite	genitals
ʊˤ	ʊˤlu	enter
ɑʕ̰	ʔɑʕ̰nɑ	toy
uʕ̰	duʕ̰bɑ	anus

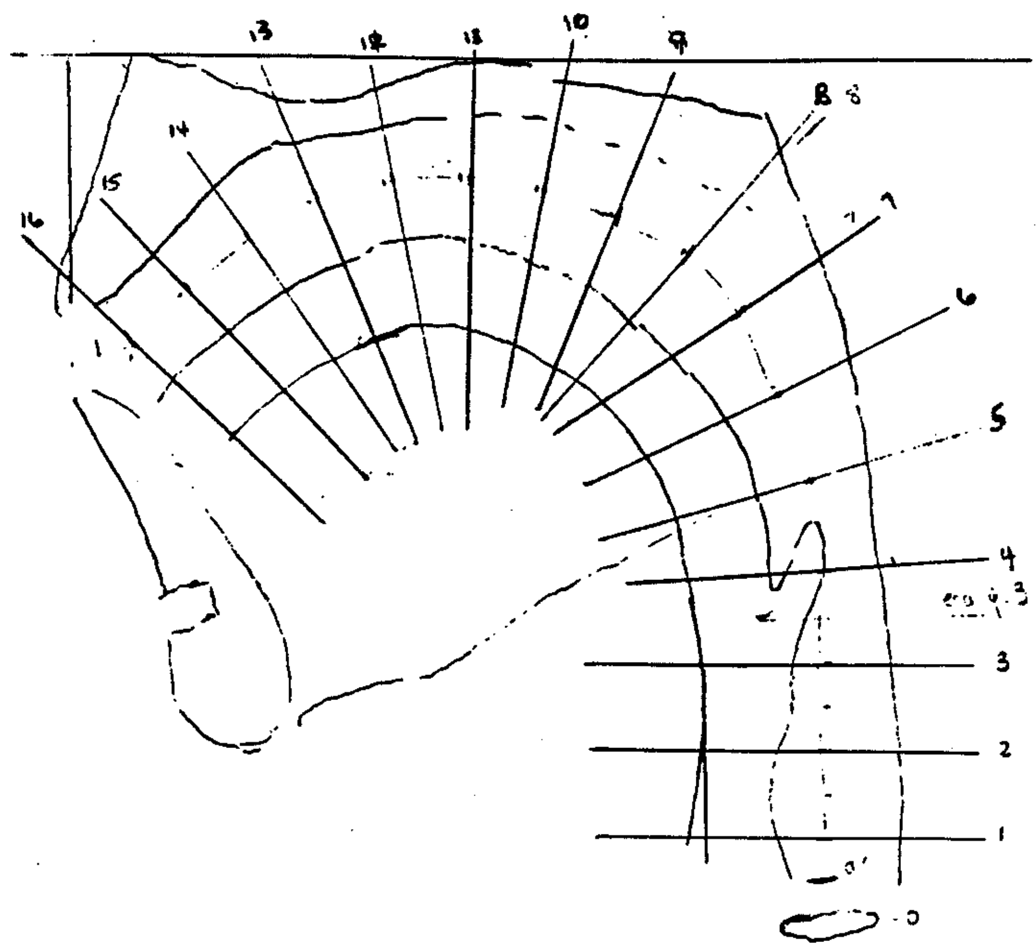
Ib. Words from which tracings of Speaker B (also referred to as Speaker 2 in the text) were made. Glosses provided by Tony Traill (p.c.).

segment	word	gloss
i	ǁɢuˤlite	genitals
e	ǂeẽ	wake up
ɑ	dt'kx'ɑlɑ	cut open
o	dtshxon	slip out of
u	ǫˤlu	enter
ɑˤ	qɑˤɑ	long ago

uˤ	ǁɢuˤlite	genitals
ʊˤ	ʊˤlu	enter
ɑʢ	n’ǀɑːʢ	father-in-law
uʢ	duʢ’n	wash it

II. !Xóõ tracings. All vowels were traced in a steady state portion in the middle of the vowel. Broken lines indicate best guess in an indistinct portion of the x-ray.

IIa. Tracings of !Xóõ Speaker G from Traill (1975). Reference numbers following segment identification list reel number/frame number.

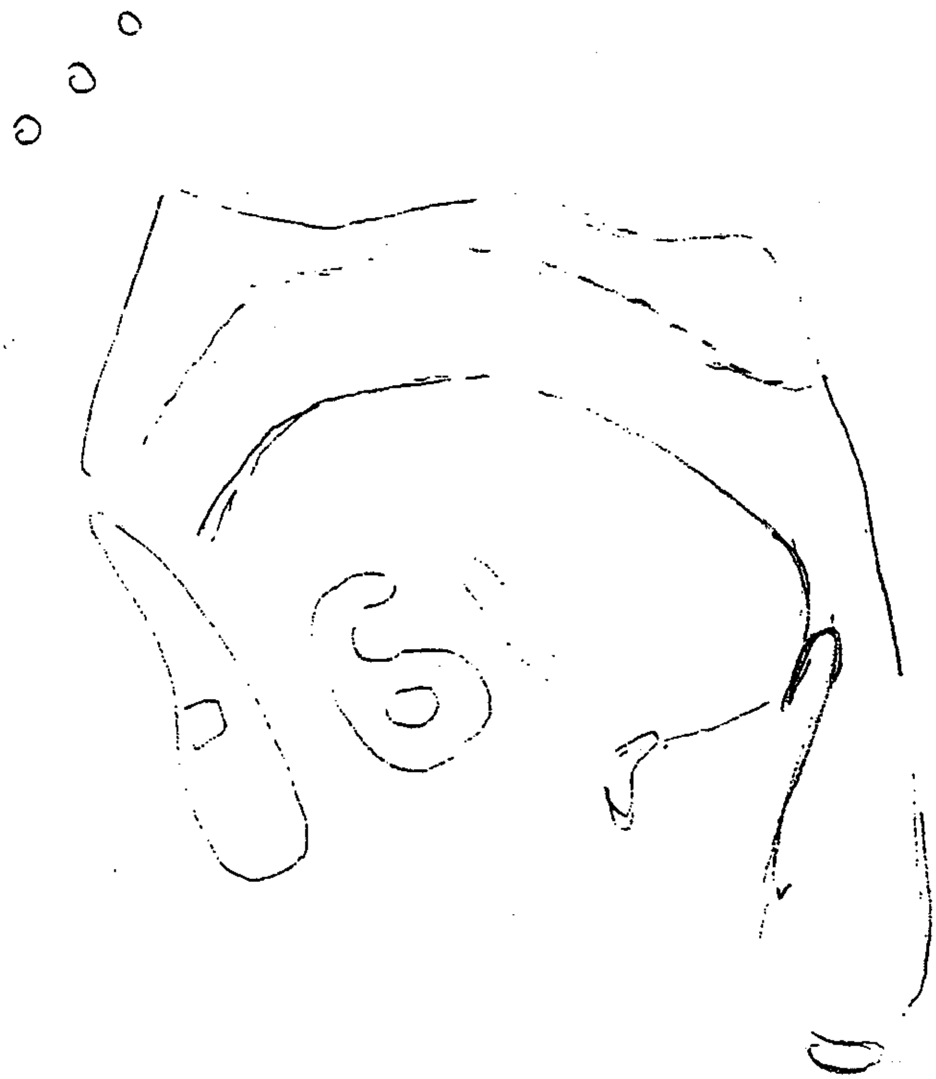


BIIa.1 Measurement grid for !Xóõ speaker G

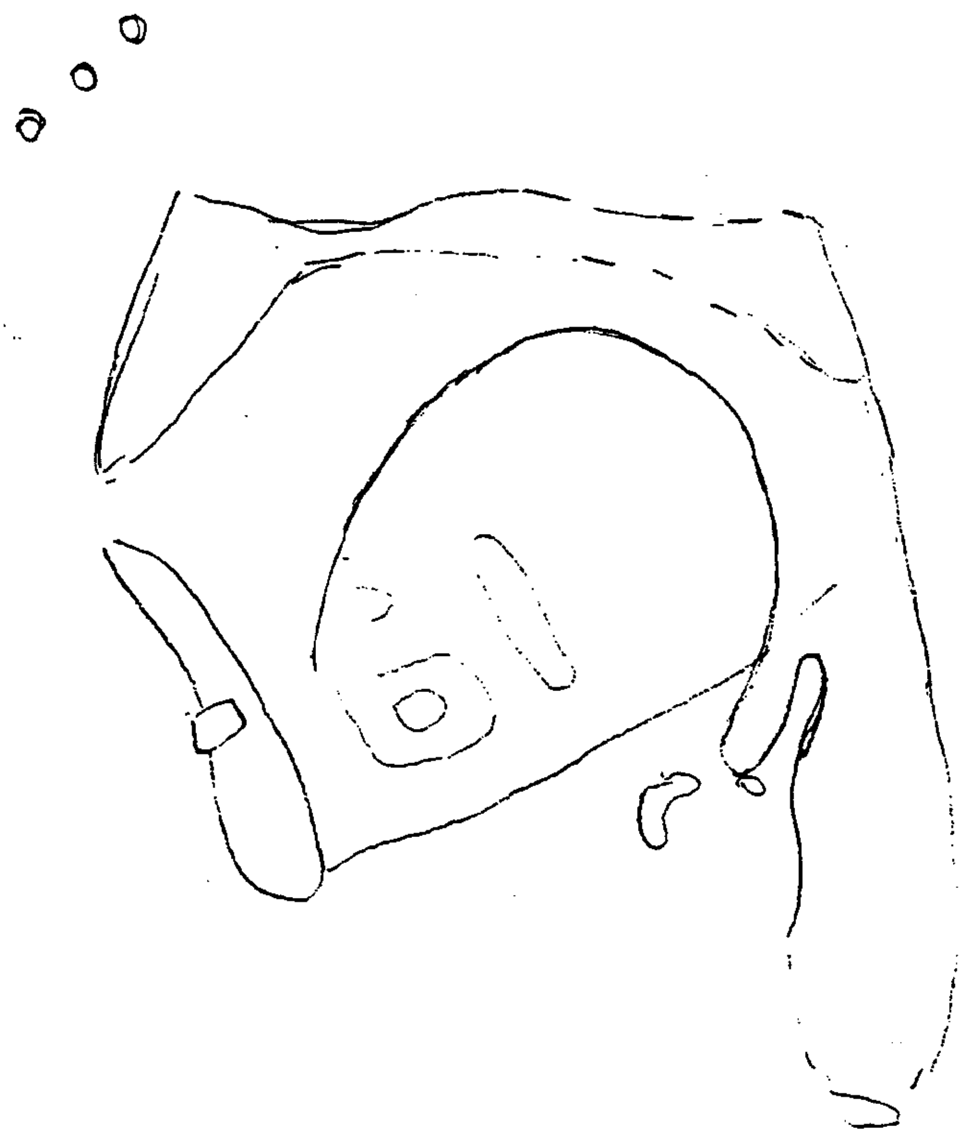
BIIa.2 !Xóõ speaker G [i] frame 4/284

BIIa.3 !Xóõ speaker G [e] frame 4/1221

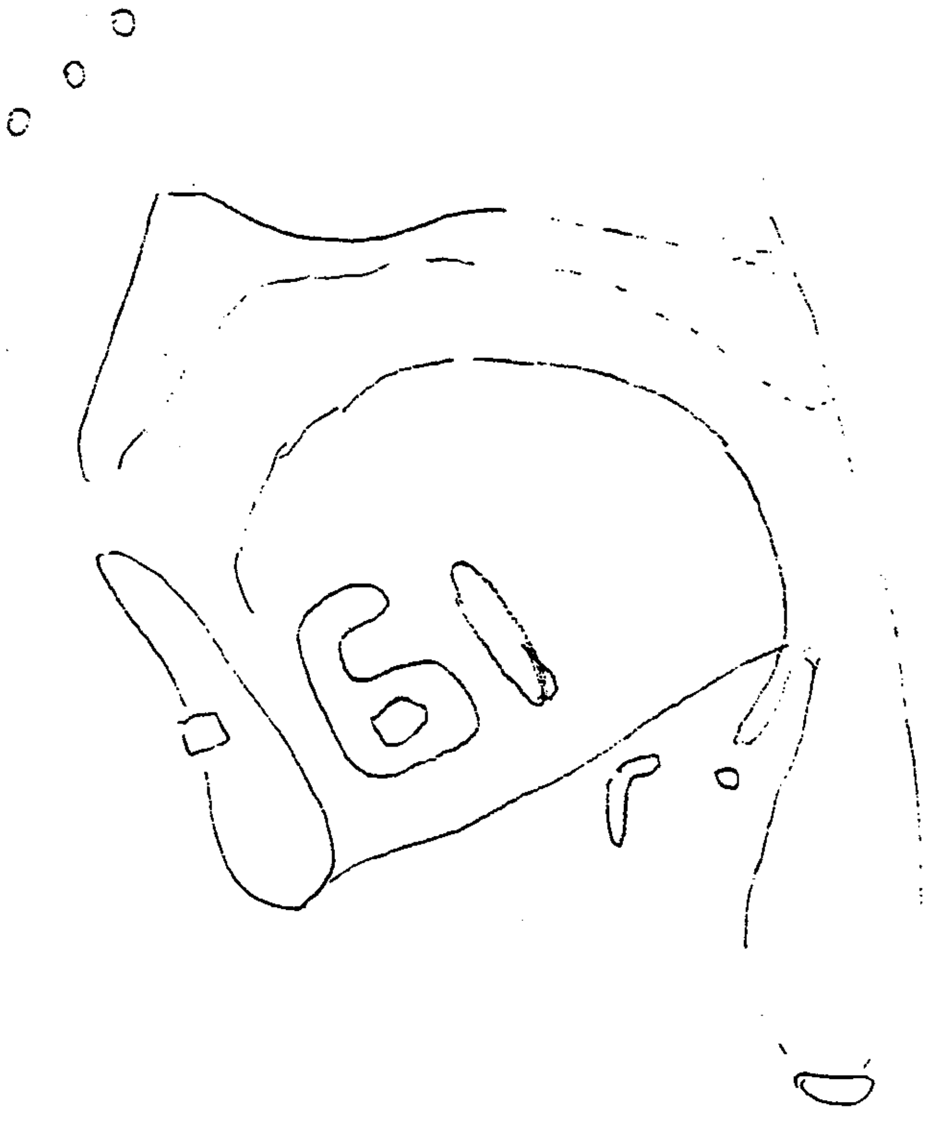
BIIa.4 !Xóõ speaker G [ɑ] frame 4/1368



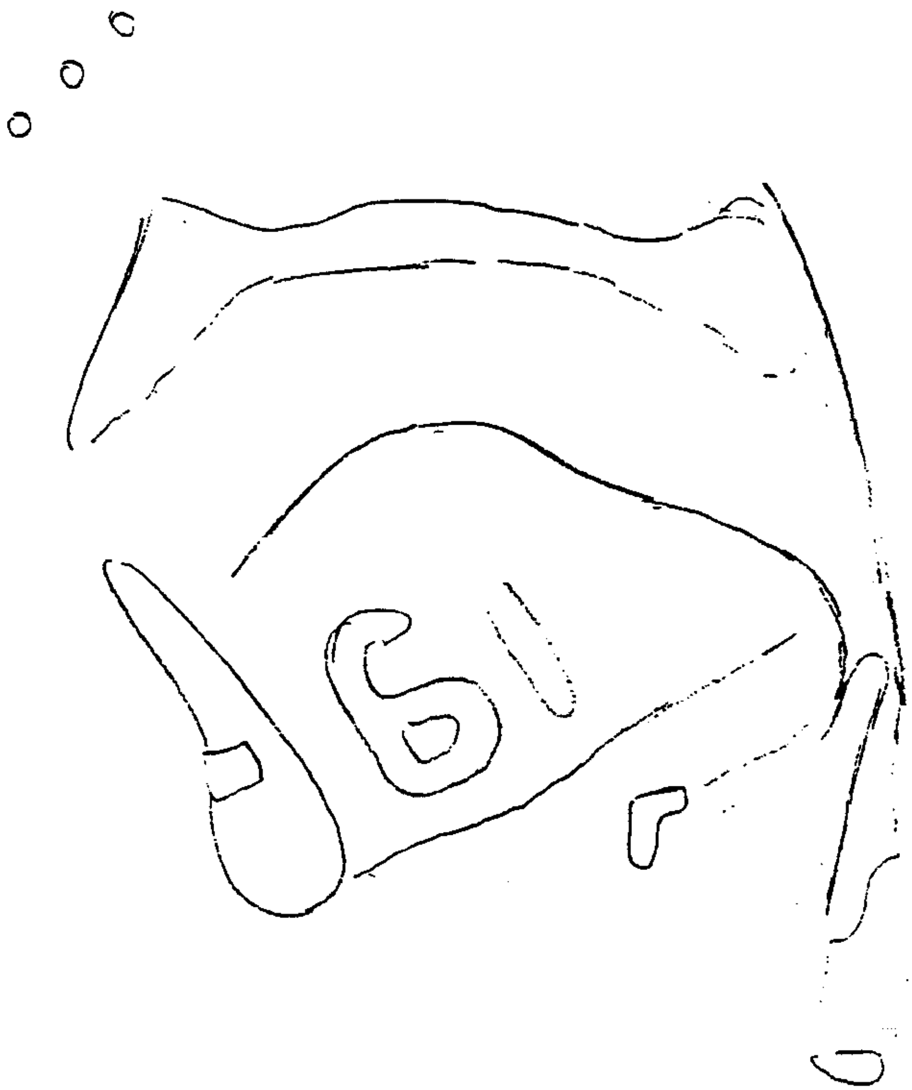
BIIa.5 !Xóõ speaker G [o] frame 4/495



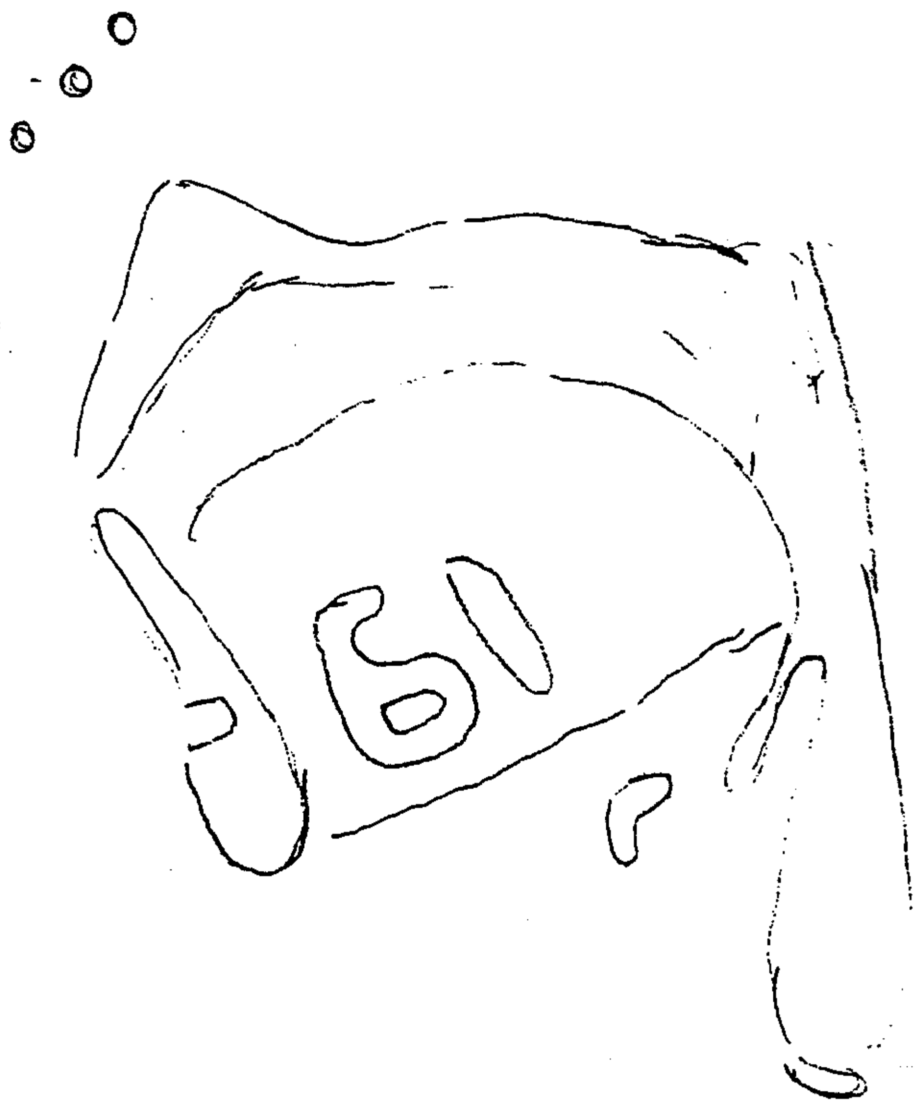
BIIa.6 !Xóõ speaker G [u] frame 4/1075



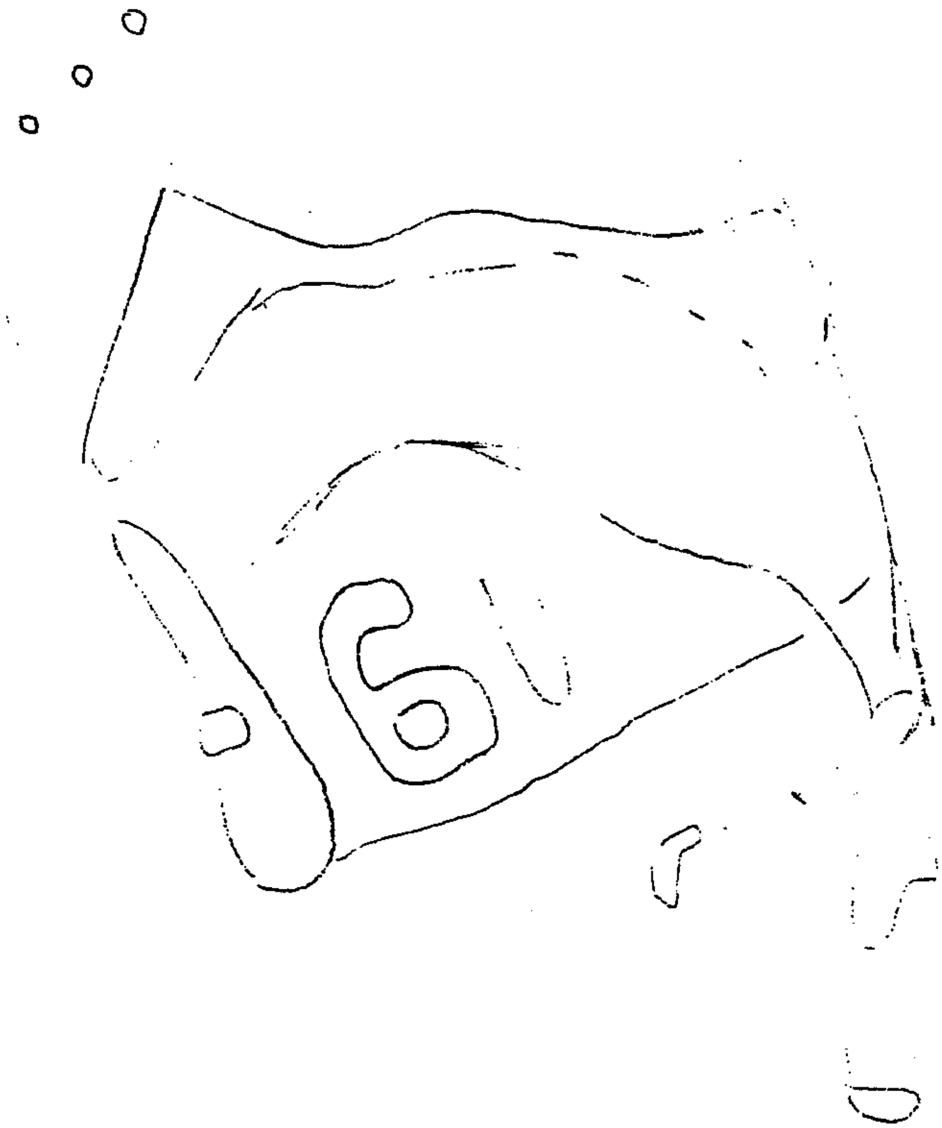
BIIa.7 !Xóõ speaker G [ʊ] frame 4/1067



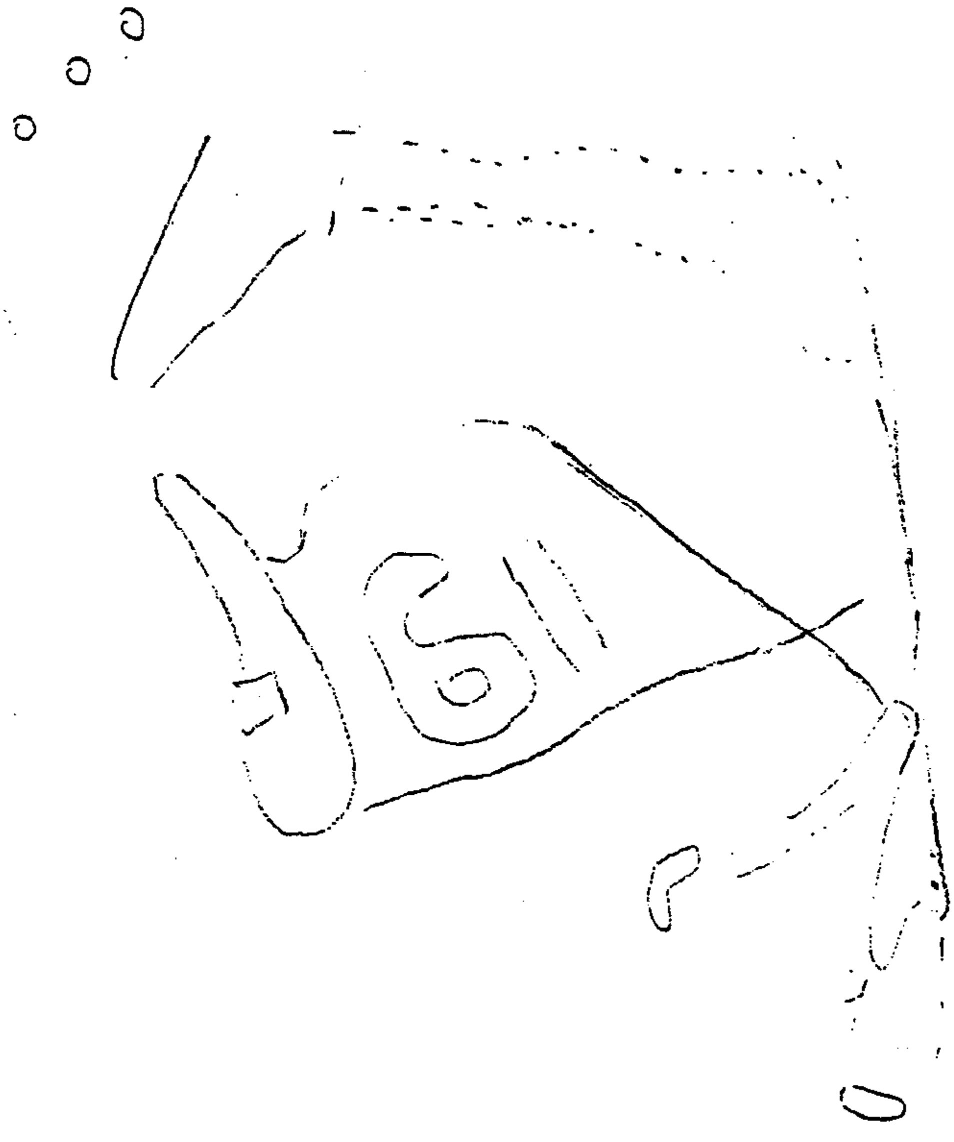
BIIa.8 !Xóõ speaker G [ɑˤ] frame 5/278



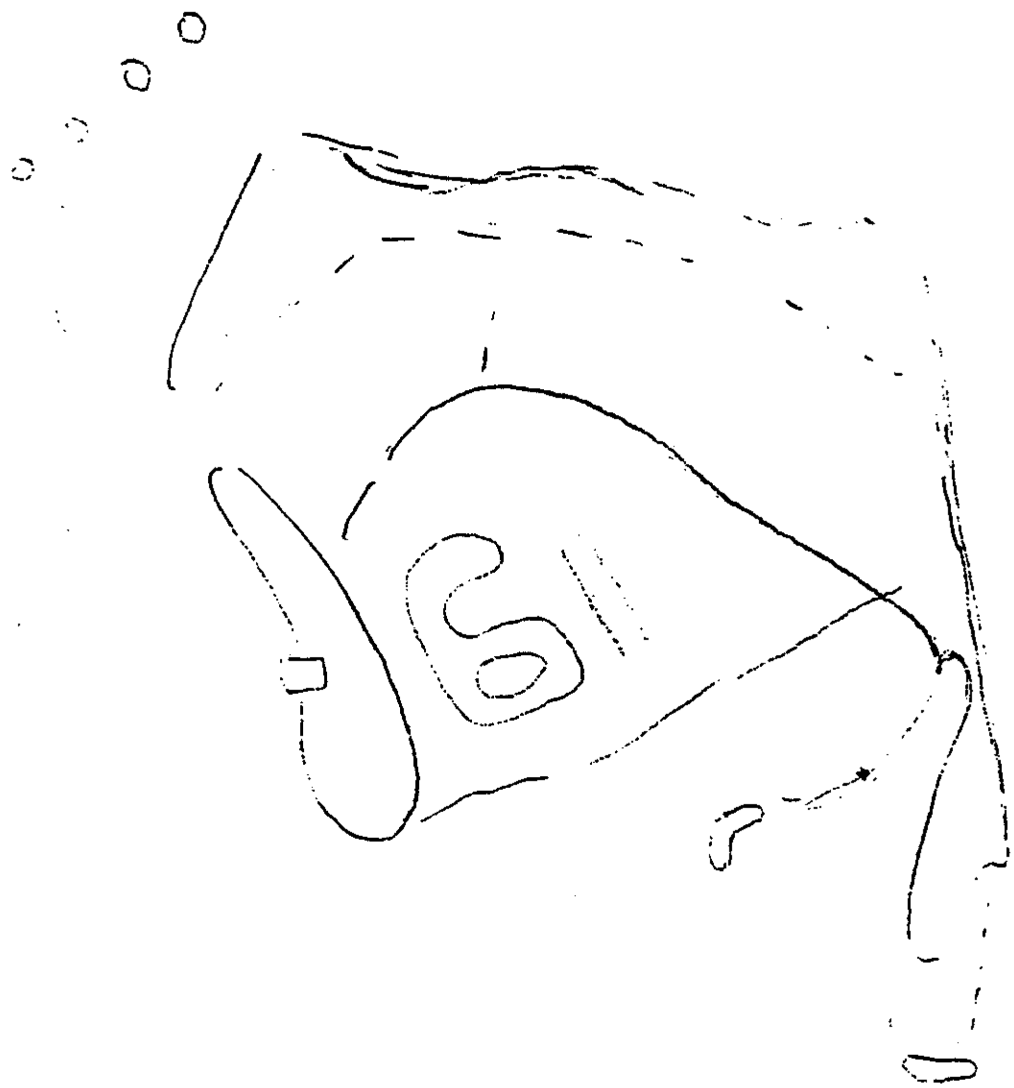
BIIa.9 !Xóõ speaker G [$u^{ʕ}$] frame 4/178



BIIa.10 !Xóõ speaker G [$o^{ʕ}$] frame 5/461

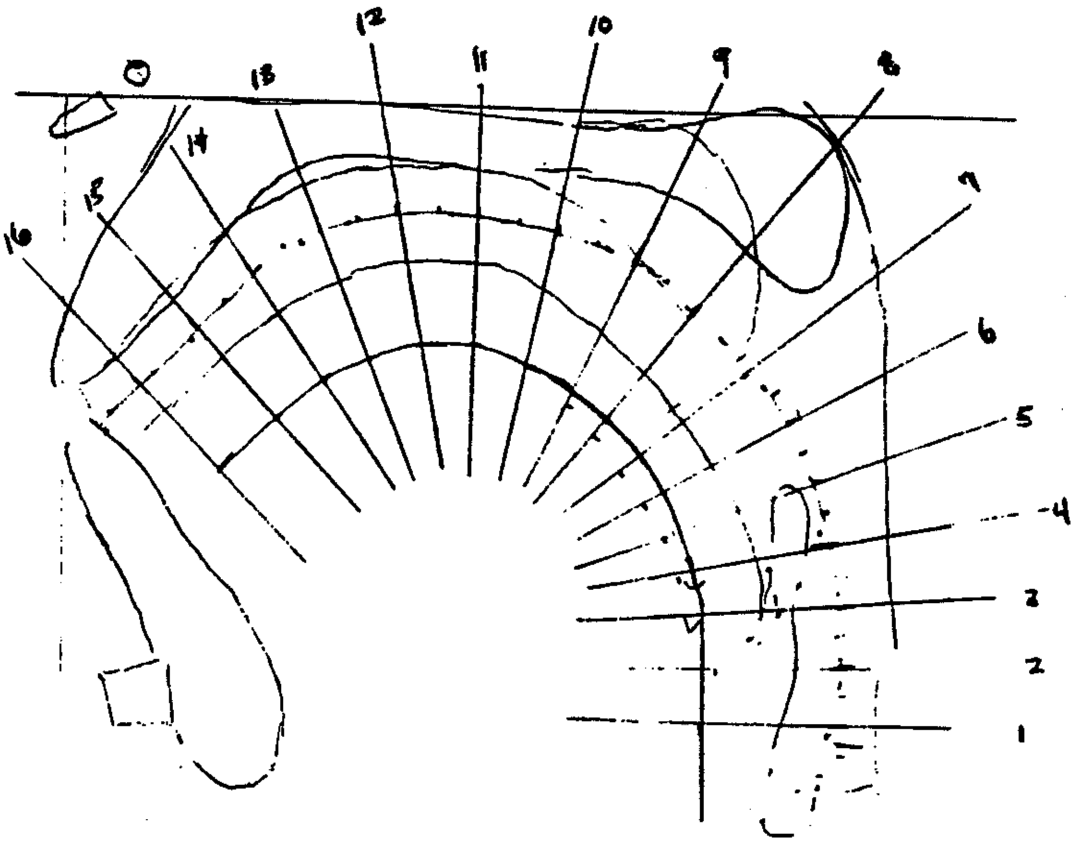


BIIa.11 !Xóõ speaker G [ɑ͡ʕ] frame 5/769

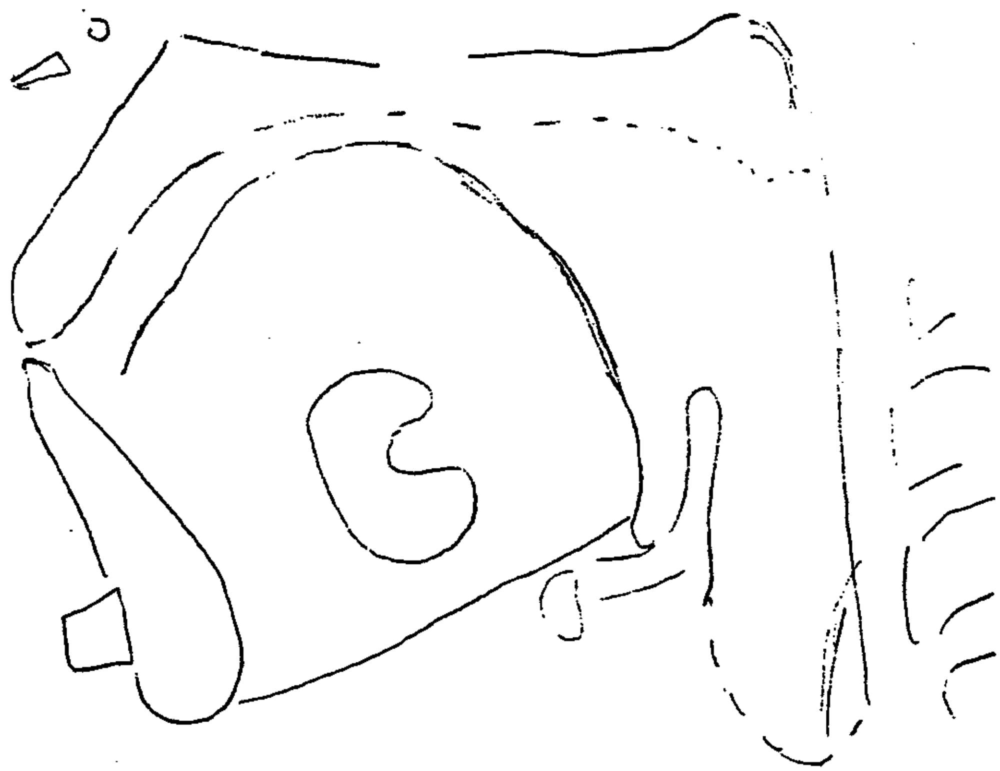


BIIa.12 !Xóõ speaker G [uʢ] frame 5/837

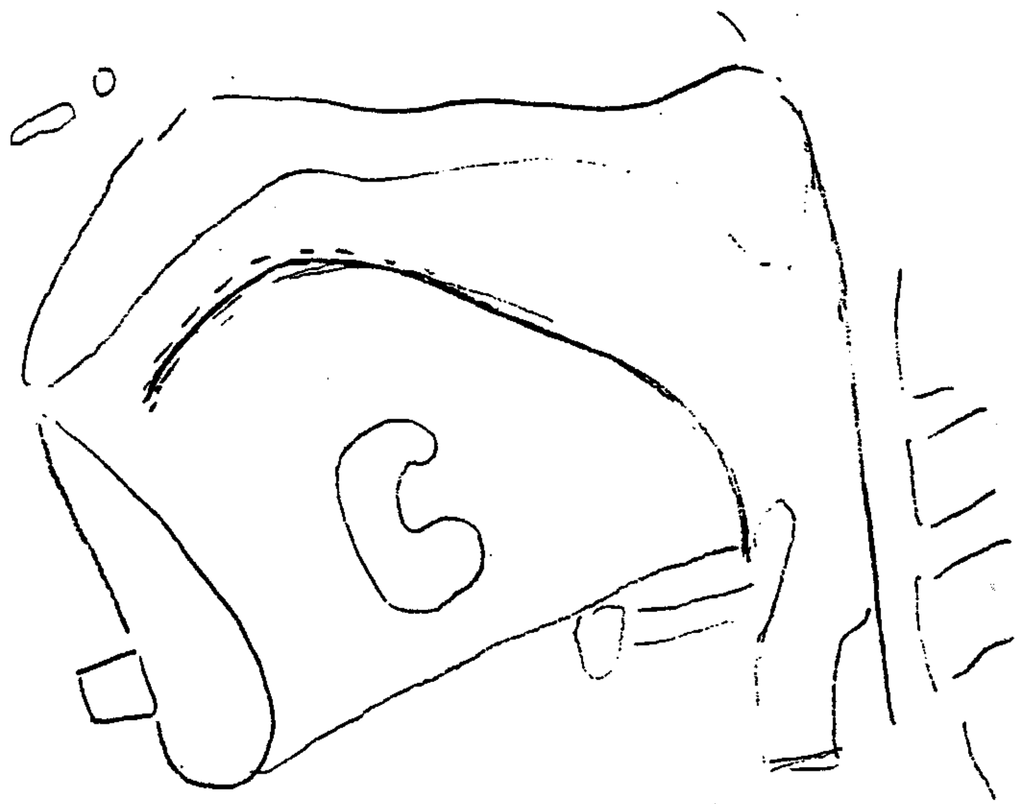
BIIb. Tracings of !Xóõ speaker B from Traill (1975).



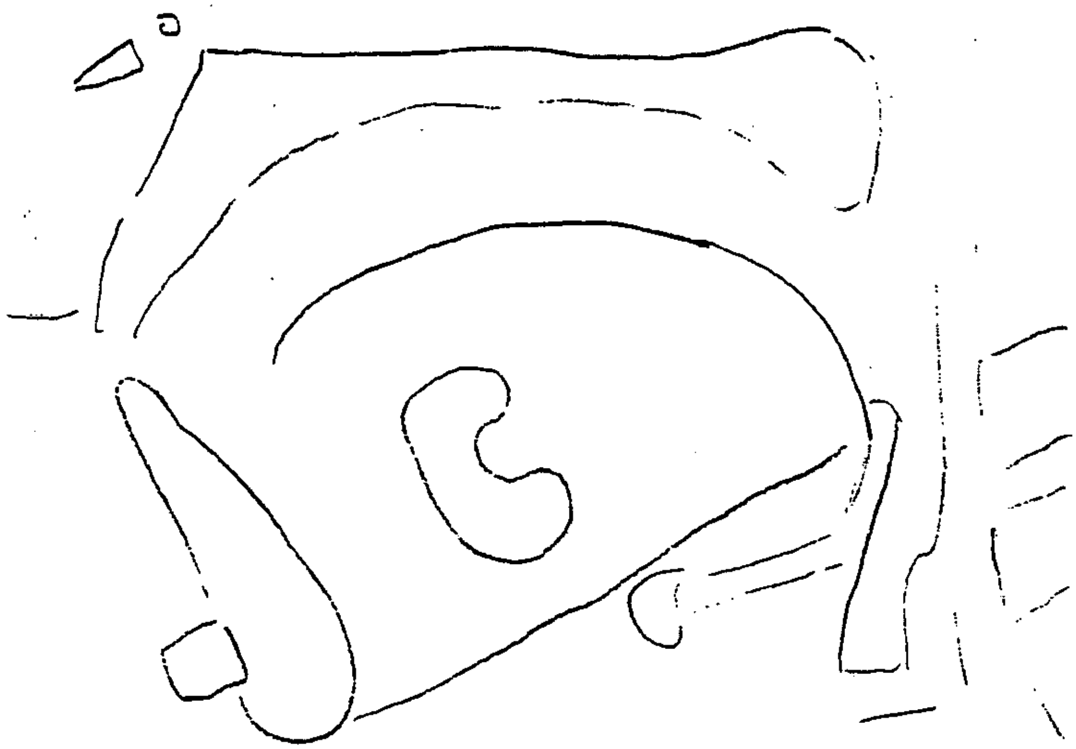
BIIb.1 !Xóõ speaker B Measurement grid frame 5/1933



BIIb.2 !Xóõ speaker B [i] frame 5/1164

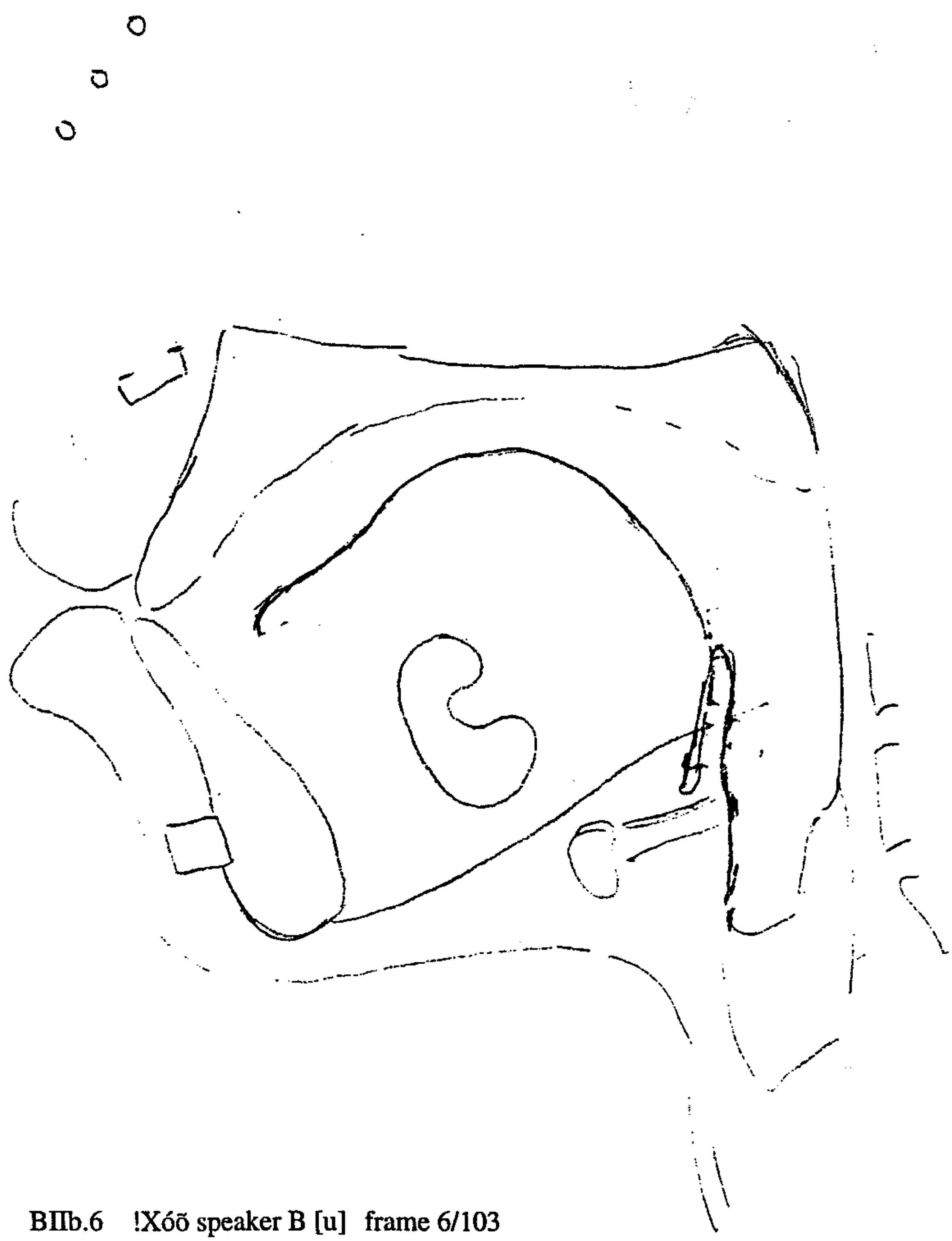


BIIb.3 !Xóõ speaker B [e] frame 5/1365

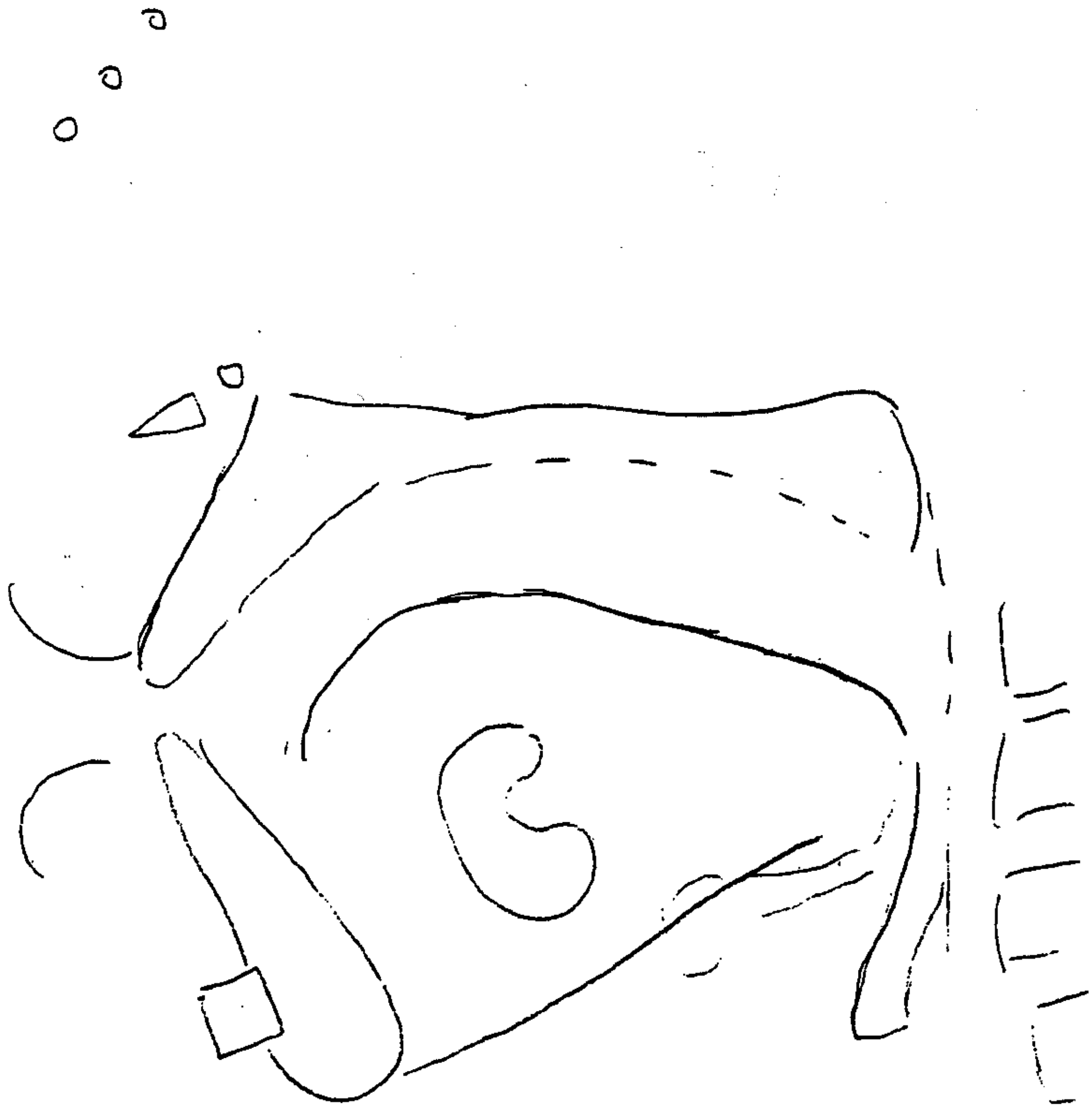


BIIb.4 !Xóõ speaker B [ɑ] frame 5/2028

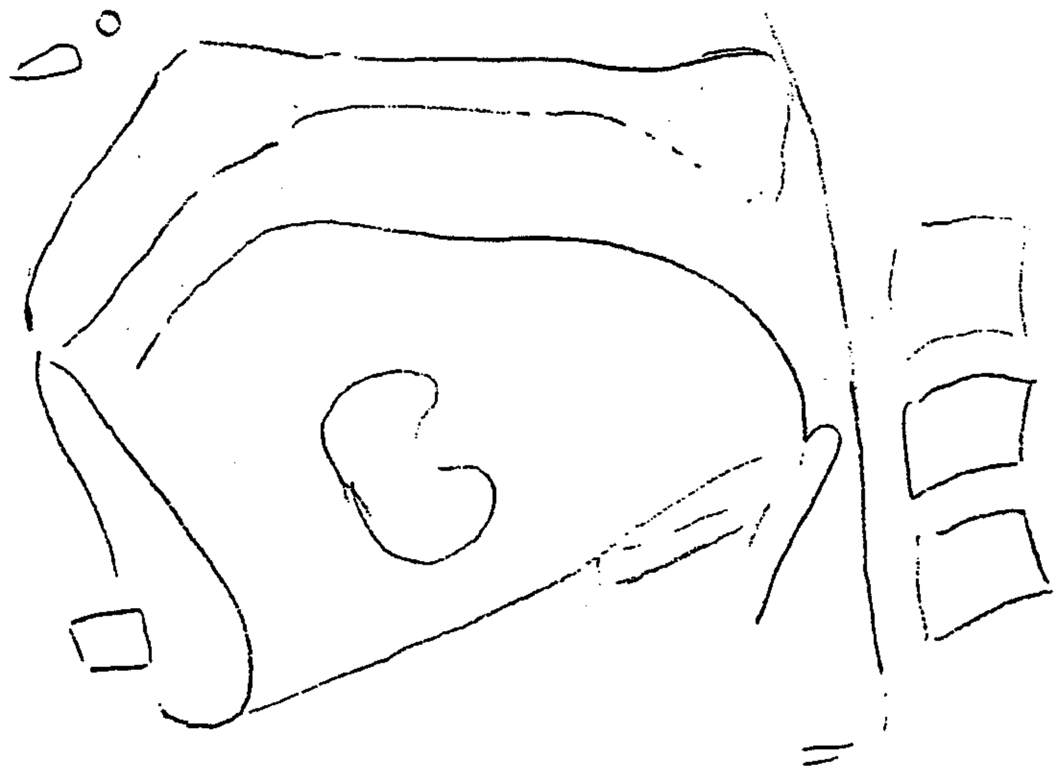
BIIb.5 !Xóõ speaker B [o] frame 5/2135



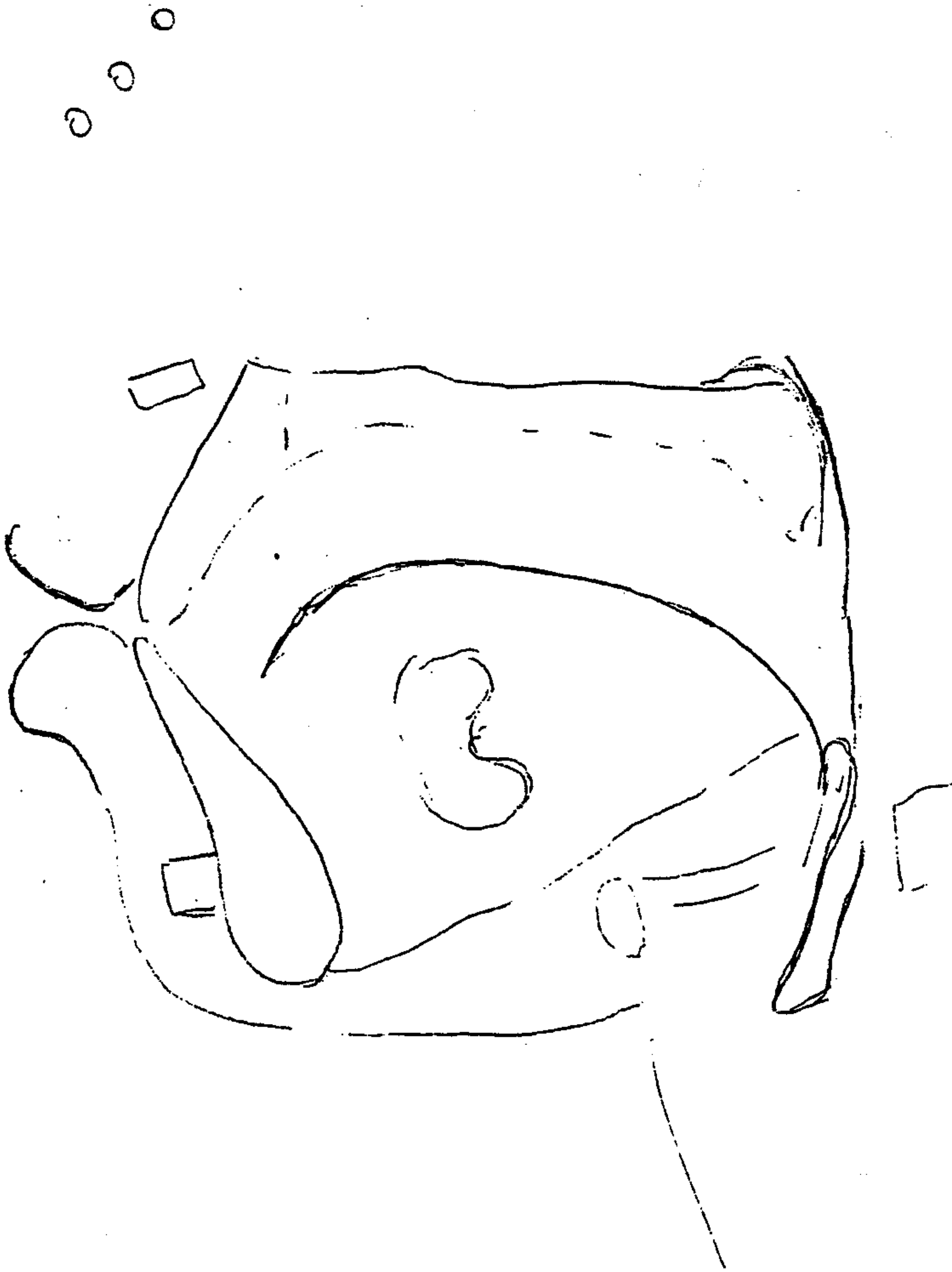
BIIb.6 !Xóõ speaker B [u] frame 6/103



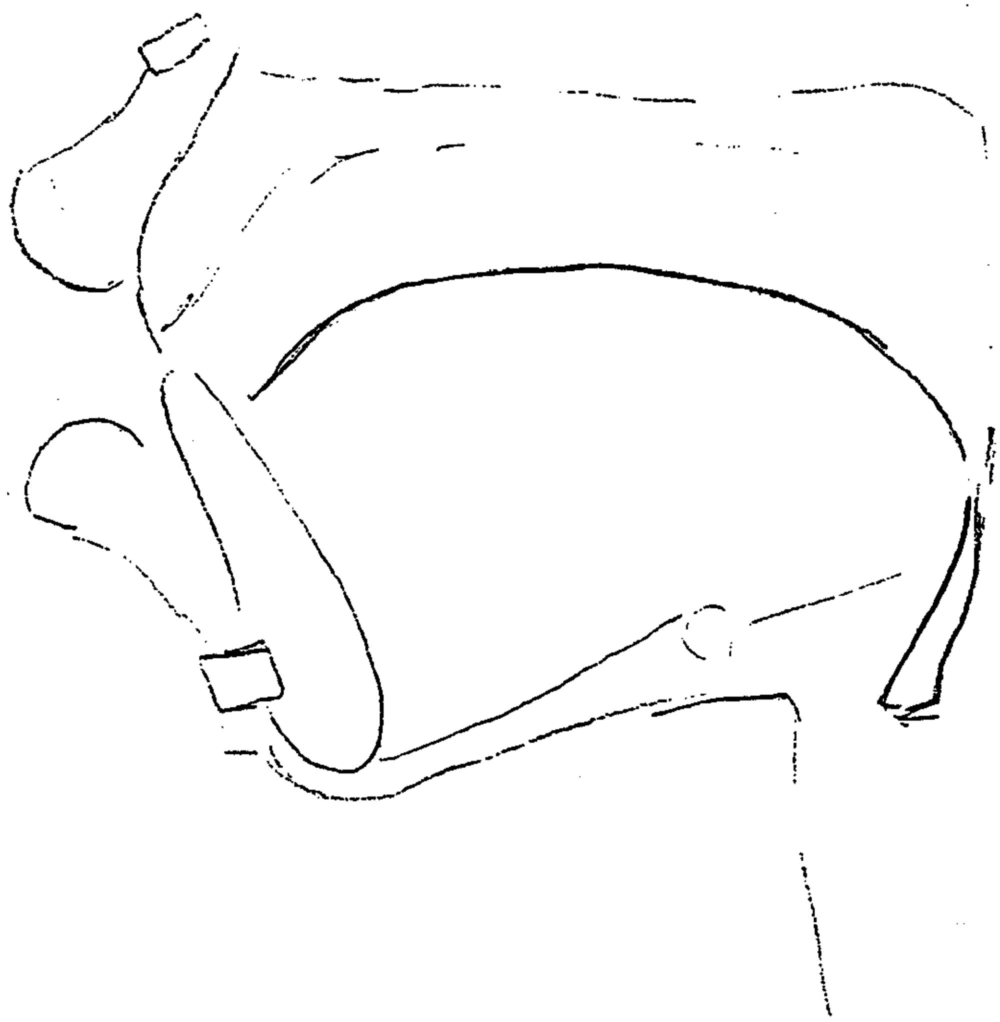
BIIb.7 !Xóõ speaker B [ɑˤ] frame 5/2259



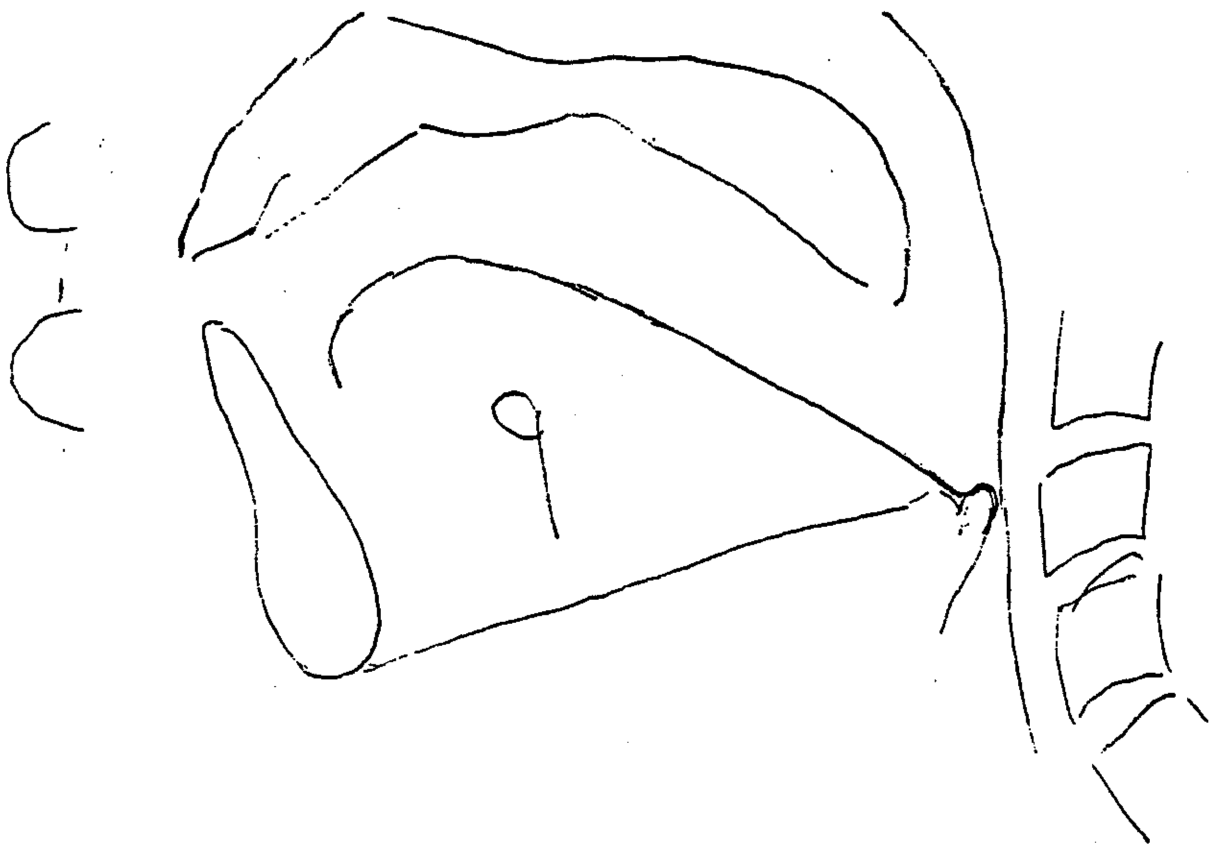
BIIb.8 !Xóõ speaker B [$u^{ʕ}$] frame 5/1081



BIIb.9 !Xóõ speaker B [ʊˤ] frame 6/91



BIIb.10 !Xóõ speaker B [ɑˤ] frame 5/2219



BIIb.11 !Xóõ speaker B [uˤ] frame 3/1143 from Traill (1972)

APPENDIX C

Articulatory loadings from the five-factor PARAFAC analysis of eleven speakers

Measure	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
e1	0.1138	0.5936	-0.5363E-01	0.33360	0.5573
e2	0.2778	0.6585	-0.2724	0.3129	0.4423
e3	0.3170	0.6661	-0.3512	0.3074	0.4628
e4	0.3582	0.6383	-0.4024	0.1423	0.4226
t4	0.4674	0.6143	-0.4927	0.2922E-01	0.2271
t5	0.6358	0.4215	-0.3999	-0.1671	0.8537E-01
t6	0.7483	0.1297	-0.1652	-0.3718	0.1311
t7	0.7922	-0.1408	0.3764E-01	-0.4362	0.7054E-01
t8	0.7786	-0.2755	0.1908	-0.4155	-0.9965E-01
t9	0.6878	-0.4592	0.2674	-0.3680	-0.4596E-01
t10	0.4869	-0.6266	0.2918	-0.1673	-0.1657
t11	-0.1094	-0.6463	0.1673	0.2512	-0.3447
t12	-0.5956	-0.4208	0.3185E-01	0.4974	-0.2870
t13	-0.7193	-0.3008	-0.1659E-01	0.4861	-0.2585
t14	-0.7494	-0.2295	-0.4359E-01	0.5199	-0.2450
t15	-0.7257	-0.1813	-0.9498E-01	0.5401	-0.2038
t16	-0.6769	-0.16751	-0.1487	0.5300	-0.1567
p1	0.1962E-01	-0.1610E-01	0.4436	0.3769	0.4738
p2	0.8397E-01	0.3995E-02	0.6872	0.4039	0.2608
p3	0.2406	0.4211E-01	0.5459	0.5453	0.4790
p4	0.2127	0.1212	0.5047	0.4234	0.5880

Measure	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
p5	0.2573	0.1157	0.5412	0.3784	0.5505
p6	0.1911	0.1273	0.5096	0.4483	0.4495
p7	0.1686	0.1961	0.4427	0.4343	0.2594
p8	0.1434	0.2115	0.2270	0.1985	0.3344E-01
lpx	-0.1214	-0.4761	0.7216	0.7455E-01	-0.2647
epi	0.1343	0.1689	0.1797	0.1560	-0.2105
lx	0.4424E-02	-0.4219	0.5676	0.2798	-0.2408
lpa	0.3686E-01	-0.2871	-0.4371	0.9944E-01	0.3947
lpp	0.1869	-0.6811E-01	0.3912	-0.2197	0.1885E-01

Mode C (Speaker) loadings for the five factors

Speaker	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Akan 1	1.129	0.6636	1.842	5.010	0.3688
Akan 2	2.504	0.3339	0.5618	0.9859	-0.4054E-01
Akan 3	0.9497	-0.7465E-01	1.260	1.973	0.3586E-01
Akan 4	3.075	0.2800	2.494	0.1493	0.2508
Ndut	1.040	0.2835	2.382	0.3828	1.095
!Xóõ 1 (G)	0.5970	5.461	0.4515	0.2120	0.1806
!Xóõ 2 (B)	0.7632	2.739	0.2212	0.1050	1.096
Ghazali	0.8736	0.5135	0.3157	0.3573	2.666
Metoui	-0.1133E-01	0.1348	1.256	0.7561	0.2459
Qatari	-0.2630	-0.8048E-01	0.1629	0.5540	4.660
Ali	0.3426	0.7465	0.5241E-01	0.5145	0.4413