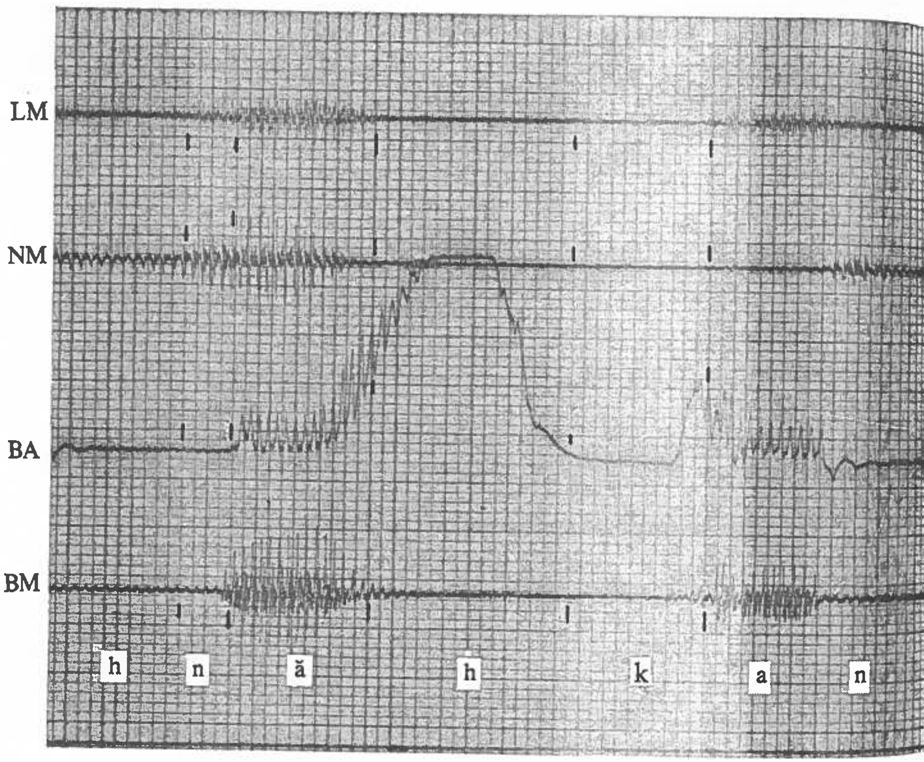

Fig. 11. Hnakkann, (phrase 7).

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A CONTRASTIVE CINEFLUOROGRAPHIC INVESTIGATION OF THE ARTICULATION OF EMPHATIC – NON EMPHATIC COGNATE CONSONANTS

Acknowledgments

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Introduction

In most languages, consonant production involves partial or complete obstruction of the vocal tract at some place between the glottis and the lips. In Semitic languages certain classes of consonants are produced with constriction of the pharyngeal cavity, in particular, between the velum and the glottis. Klatt and Stevens (1969) have shown that such consonants with a constriction well back in the vocal tract have the distinctive property that Formant 1 is high and relatively close to Formant 2. This makes it possible to distinguish between pharyngeal consonants and consonants with a more anterior constriction, the latter of which are characterized by a low-frequency first formant.

Speech sounds produced by using constrictions between the velum and tongue, or tongue and pharyngeal walls are traditionally known by phoneticians as emphatic sounds; Blanc (1953), Ferguson (1957, 1963), Lehn (1963), Harrell (1960), Yushmanov (1961), Jakobson (1962).

The term 'emphatic' is a modified translation of the Arabic word 'mufaxxama' which is related to the features 'tense' and 'pharyngealized' combined together. As a matter of fact the word 'tafxiim' (noun of 'mufaxxama') is related to several distinctive features when used by Arab grammarians, such as 'tense,' 'long,' 'flat' or 'back.'

Jakobson quotes Gairdner's (1925) simple and naive instructions to his students to master producing the voiceless pharyngeal fricative [ḥ], by pronouncing an ordinary glottal [h] and, "try to tighten the pharynx during its production" (p. 518). Jakobson states that still X-rays reveal the projection of the tongue root toward the posterior pharyngeal wall with a resulting reduction of the pharyngeal aperture of 1 cm for [ṭ] as vs. [t] and 1.5 cm for [ḍ] vs. [d]. Other than Jakobson's brief description above, there is no definitive study concerning the differential articulation patterns involved in the production of emphatic vs. non emphatic cognate consonants. Speculations about how sounds like [ṭ] and [t] are differently articulated must be put to empirical test.

Statement of the problem

Studies of articulatory movements during speech production have shown that the single most important articulator is the tongue. However, the basic details of the tongue functioning are still obscure, particularly when the question touches the emphatic sounds, especially the role of the tongue root and its relation with the pharynx.

This study is an attempt to demonstrate and to quantify the physiological activities of the tongue root, the velum, the posterior pharyngeal wall, and the hyoid bone during the articulation of contrasting Arabic emphatic and nonemphatic consonants.

The specific purposes of this study are as follows:

1. What precisely are the differences and similarities in the shape and movement patterns of the tongue root for various emphatic and nonemphatic Arabic consonants?
2. What behavior(s) does the velum adopt for each of the consonants with respect to velar height and timing of movement?
3. What movement patterns characterize the pharyngeal walls during the emphatic and nonemphatic consonants?
4. Are there timing differences for any other major articulator movements which could differentiate emphatic from nonemphatic consonants?
5. How does R-L (right-to-left) and L-R (left-to-right) coarticulation of 'emphaticness' over adjacent vowels vary as a function of emphatic or nonemphatic consonants in both meaningful and meaningless words?
6. Can a general mechanism be proposed to account for a single articulatory distinctive feature, emphatic vs. nonemphatic?

Procedures

The general procedure of this study consisted of obtaining cinefluorographic films of three subjects producing selected nonsense syllables and words at conversational effort level and rate. The analysis of the films was made from measurements obtained from tracings of individual film frames. Comparisons between emphatic and nonemphatic consonants and their accompanying vowels were made from measures of the tongue dorsum position, velum positions, and the pharyngeal wall movements.

Equipment

The cinefluorographic equipment used was manufactured by the North American Philips Company. The array consisted of a Rotalix 0-75/125 KVP X-ray tube with 0.6 mm² focal spot and high speed rotary anode, a 300 ma generator with a smoothing capacitor, and a nine-inch image intensifier tube having an intensification factor of approximately 3000X. A Mitchell 600 camera (16 mm.), capable of film speeds up to 600 frames per second was used with Eastman Plus-X Reversal (type 7276) film. Each subject was seated upright in an adjustable Philips dental chair, and the central X-ray was made to impinge upon the center of the intensifier tube receiving screen. The subject's head was held firmly in a head positioner consisting of ear rods and forehead bumper.

The speech sample recording was made by using an Electro-Voice 644 dynamic, unidirectional microphone, whose output was led to one channel of a Magnacord, model 728 two channel tape recorder. Two native speakers of Arabic who were also students of linguistics were called upon to provide phonetic transcriptions of each subject's speech recorded during the filming of the sequences.

Subjects

Three male adults were used as subjects. All were native speakers of Iraqi Arabic, Baghdad dialect. The three subjects displayed "normal," misarticulation-free speech. None showed any apparent oral-facial organic pathologies or excess dental fillings.

Speech Samples

The speech samples consisted of CV and VC sequences where C = emphatic or nonemphatic consonant, and V = [i, a, u] and [I, æ, U], that is, long and short vowels. The C was the emphatic bilabial voiced stop [ḅ] and its nonemphatic counterpart [b]; the alveolar emphatic fricative [ṣ] and nonemphatic cognate [s]; the alveolar emphatic voiceless stop [ṭ] and nonemphatic [t]; and the (post)velar emphatic [ḳ] and nonemphatic [k]. Tables 1 and 2 show the combinations of these consonants with the above vowels in meaningless disyllables and meaningful words respectively. For the nonsense sequences, the first syllable of CVCV received the primary stress. Normal Baghdad Arabic stress pattern was used for the meaningful words; that is, in CVCVCVC and CVCVC, where the last syllable is a closed one, the primary stress falls on the final syllable, otherwise it is received by the first syllable. The six consonants were also produced in an [ʌ—ʌ] environment in order to establish consonant "reference-target" frames at the point of consonantal closure or occlusion steady state.

Table 1. Nonsense sequences used to assess the articulary behavior of the tongue dorsum, velum, and posterior pharyngeal wall. The same sequence was repeated using the consonants [ḅ] [b], [ṭ] [t], and [ḳ] [k].

	Emphatic	Nonemphatic
with long vowels	[ṣiṣi]	[sisi]
	[ṣaṣa]	[sasa]
	[ṣuṣu]	[susu]
with short vowels	[ṣIṣI]	[sIsI]
	[ṣæṣæ]	[sæsæ]
	[ṣUṣU]	[sUsU]

Table 2. Meaningful sequences (words) used for the study of the coarticulation of the feature 'emphatic.'

Emphatic	Nonemphatic
[ṭæbašir]	[tæbašir]
[ḳælb]	[kælb]
[ḳæṣIr]	[ḳæsIr]
[ḳæṣ]	[ḳæs]

Experimental Procedures

At the time of training, each subject read the list of the experimental sequences as many times as needed for familiarity in the presence of the experimenter. Sufficient time intervals between the successive syllable productions were allowed to eliminate the possibility of overlap of sequences.

Each subject was seated in the dental chair and the microphone placed about six inches directly in front of his mouth. Then the subject was asked to speak all the experimental sequences at a satisfactory normal conversational rate and effort level. The midline of the tongue from tip to the pharyngeal dorsum, and the lips were coated with a barium sulfate solution immediately prior to the filming, in order to achieve maximum contrast of the articulators. The X-ray ensemble and camera were turned on and filming was done at 100 frames per second.

Analysis Procedure

The activity of the tongue root, velum, the hyoid bone, and posterior pharyngeal wall was assessed by measurement along reference lines D, E_1, E_2, E_3, E_4, etc. (see Figure 1) upon which template was superimposed tracings of tongue, velum and posterior pharyngeal wall contours as traced at pre-designated time points during the experimental VC and CV sequences. The nonsense syllables were used to facilitate the comparison of emphatic vs. nonemphatic cognates so that the significant physiological differences could be easily observed. On

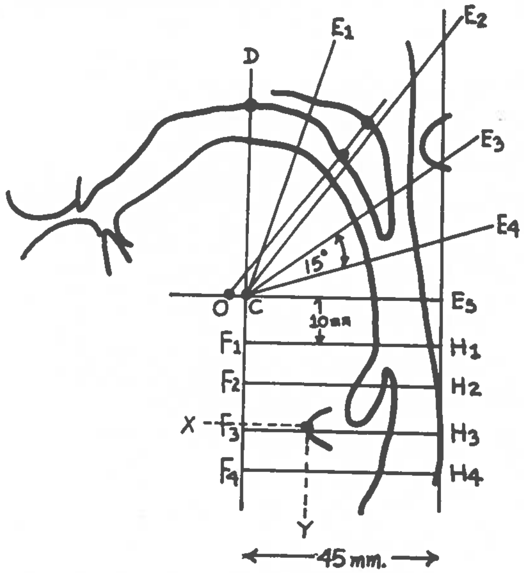

Fig. 1. Tracing grid for measurement of tongue, velum, hyoid bone, and posterior pharyngeal wall positions.

the assumption that meaningful words are articulated differently from nonsense items, a number of meaningful word pairs with the emphatic-nonemphatic contrast, Table 2, were prepared so that possible differences between the emphatic and the nonemphatic pairs as a function of a natural, meaningful context could also be observed.

Use of the emphatic vs. nonemphatic consonants, that is [ḅ] [b], [ṣ] [s], [ṭ] [t], and [ḳ] [k] provided opportunity to study differences in pharyngeal constriction, palatal height, back pharyngeal wall position and timing of their movements, in many different positions along the vocal tract. The six vowels were chosen to reflect a range of positions within the vocal tract as well as a tense/lax difference. Frame-by-frame tracings were made for all of the experimental sequences uttered by each subject beginning with each sound on either side of the sequence of interest. Each individual frame selected for analysis was projected to life size for tracing by a Kodak Analyst 16 mm. movie projector. A handmade tracing frame which allowed image projection directly onto the tracing paper was used.

Measurements

Certain of the measurements derived from the tracings are based on reference lines for each subject. Such reference lines were derived by modifying the reference system used by Kent and Moll (1969) in their study of the vocal tract characteristics of the stop cognates, and the measurement systems of MacNeilage and DeClerk (1968), Amerman (1970), and Perkell (1969).

An outline of each subject's maxilla, upper central incisors, tubercle of the Atlas, and the posterior pharyngeal wall was made from lateral X-ray motion pictures of these oral structures at rest for use as a tracing template on which reference lines were placed. The first such reference line was drawn tangent to the posterior pharyngeal wall and is considered to be vertical. Then, another line was drawn vertically through the highest point, D, of the inferior surface of the outline of the hard palate, parallel to the line tangent to the posterior pharyngeal wall. Point C was located on the vertical line through D, so that the distance DC was the same as the perpendicular distance between the two vertical lines. Point C is the center of a circle tangent to part of the posterior pharyngeal wall and the inferior surface of the palate at D. From C radii of the circle were drawn, spaced at equal angles. Perpendicular to the vertical lines beginning at point C were a series of parallel, equally spaced reference lines F_1—H_1, F_2—H_2, F_3—H_3, F_4—H_4, and F_5—H_5 (see figure 1).

Measurements of the tongue and posterior pharyngeal wall movements were made along lines D through F_4. This was done by placing the cineradiograph tracing upon the tracing template, and aligning the two at the upper incisor and the tubercle of the Atlas. Then, using a ruled millimeter measure, the distance from point C or points F_1—F_4 to the tongue surface and/or posterior pharyngeal wall surface was measured. This was done for one frame from the center of each emphatic-nonemphatic consonant pair, and one from the center of each vowel accompanying the emphatic-nonemphatic consonant pair. Difference scores between the emphatic and nonemphatic members of a pair along each reference line were calculated and constituted much of the data used for further analysis.

Velar movement was measured along a line A—K established for each subject. A—K represents the line connecting the velar eminence of the superior surface of the velum during contraction for [s] production, and that for the velum at nonphonatory rest.

Hyoid bone movement was measured by following point XY, which represents the vertical and horizontal displacements of the frontmost point of the hyoid from line CD and line F_4.

Further Observations

Observations of certain other articulatory phenomena such as segment duration, differences in articulatory movements, contact durations, and timings of articulation movements, were made from the films.

Reliability Analysis

To assess the reliability of the tongue movement measure, 70 cine-frames were randomly selected for retracing and remeasuring. The mean differences along the reference lines D, E_2, E_4, F_1, F_4 between the test measurement and the experimental measurement were found to be 0.64 mm, 0.21 mm, 0.12 mm, 0.65 mm, and 0.36 mm respectively. These data indicate satisfactory reliability.

Results

Examination of Figure 2 shows evidence of the active role of the palatine dorsum and the pharyngeal dorsum of the tongue in differential emphatic-nonemphatic sound production. In general the palatine dorsum is depressed and the pharyngeal dorsum moved rearward for the emphatic sound relative to the nonemphatic cognate. Each difference score represents the position (p) of the tongue along the various reference lines for emphatic or nonemphatic consonants and their accompanying vowels. Difference = P (emphatic)—P (nonemphatic).

Figure 3 shows the difference scores for tongue position along the various reference lines for the emphatic-nonemphatic consonant pairs and their accompanying vowels in nonsense syllables. The emphatic consonants generally display a depressed-low position for the anterior portion of the tongue (palatine portion of the tongue dorsum) as measured along reference lines D, E_1 and E_2. The pharyngeal portion of tongue dorsum, reference lines E_3—E_5, is generally moved rearward for the emphatic consonant in contrast to its nonemphatic partner. The vowels accompanying the emphatic consonants display a similar tongue movement rearwards, towards the posterior pharyngeal wall

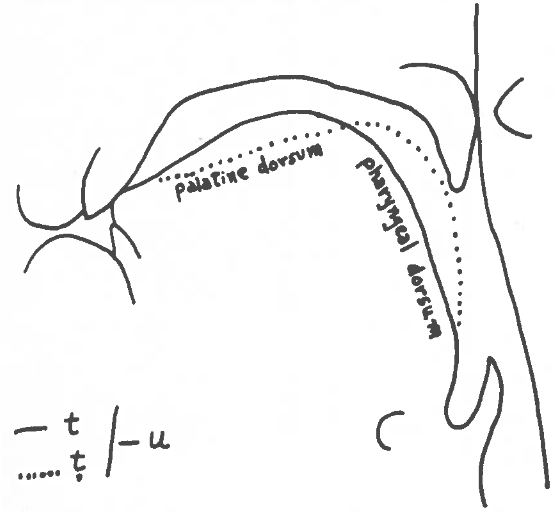

Fig. 2. A sample cine frame showing differences (in mm.) in tongue position for contrasting emphatic-nonemphatic consonant cognate pair.

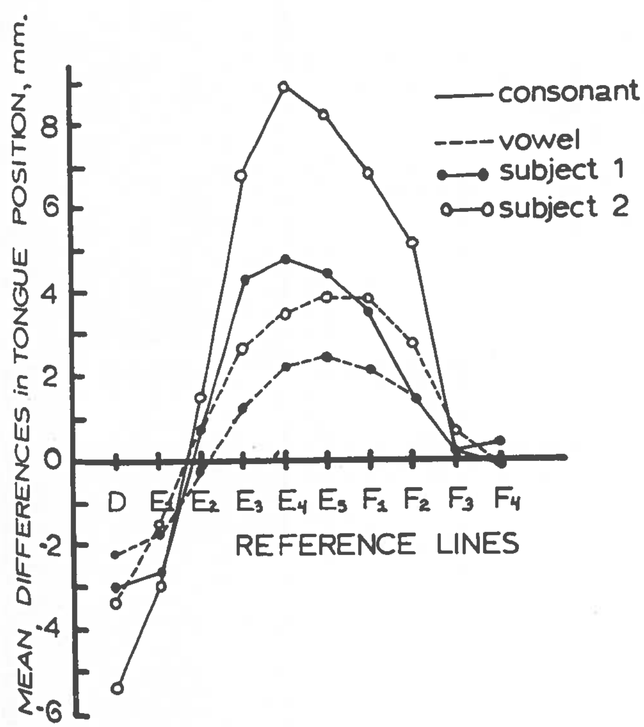

Fig. 3. Mean differences in tongue position (in mm.) between emphatic-nonemphatic cognate consonants and their associated vowels in nonsense words. Data represent mean values over all consonants and all vowels for Subjects 1 and 3.

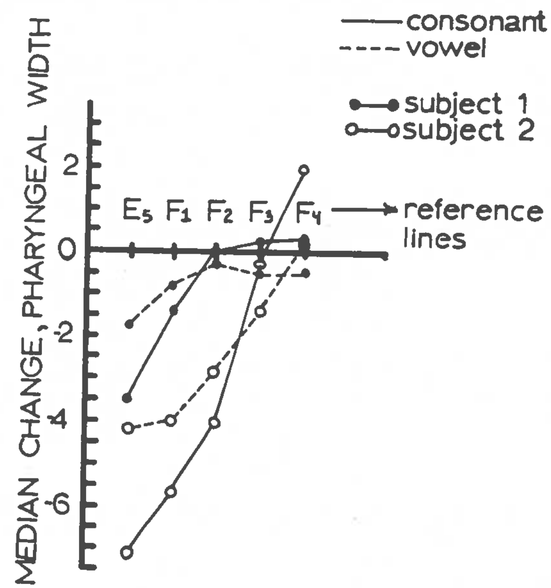

Fig. 4. Median change in pharyngeal cavity width (in mm.) between emphatic and nonemphatic consonants and their associated vowels in nonsense words. Data represent median values over all consonants and all vowels for Subjects 1 and 2.

except that the vowels display only about one-half as much backing movement. Subjects 3 shows about twice the over-all movement that Subject 1 does. For emphatic consonants and their accompanying vowels in nonsense syllables, the movement backwards (up to 4.5 mm for Subject 1, and 8.8 mm for Subject 3) is greatest at the level of the resting palate, reference line E_4, decreasing steadily towards reference lines F_3 and F_4 (immediately supraglottal) where there is essentially no differential tongue movement for the emphatic and nonemphatic consonants.

Figure 4 shows changes in pharyngeal cavity width which at reference line E_5 in the case of consonants are as great as 3.5 mm for Subject 1, and 7.0 mm for Subject 2 for consonants. Changes of pharyngeal cavity width at line E_5 for the accompanying vowels in CVCV nonsense words of up to 2.0 mm for Subject 1 and 4.1 mm for Subject 2 were also observed. These large changes in pharyngeal cavity produce marked shifts in C and V acoustic spectra which undoubtedly

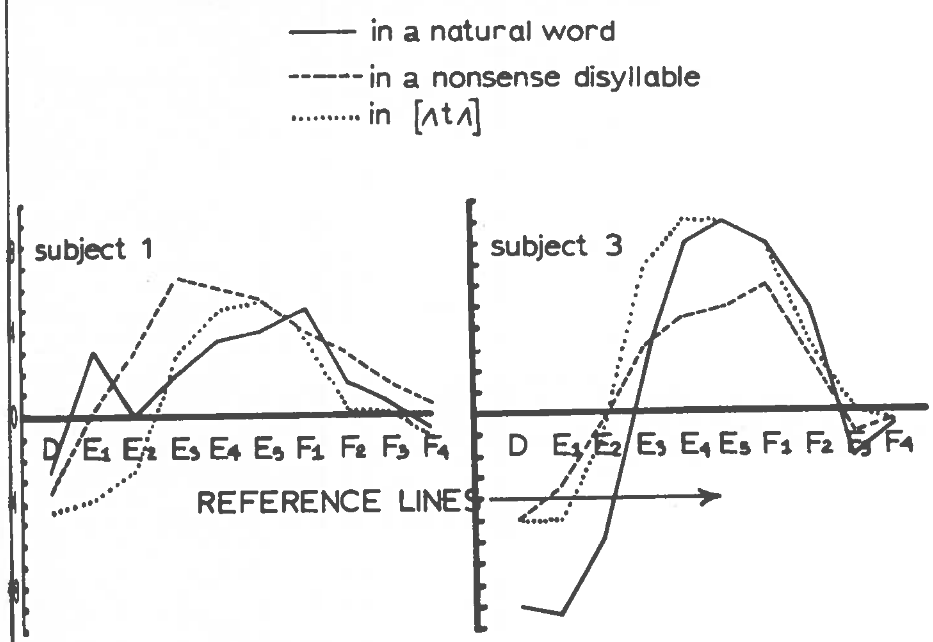

Fig. 5. Differences in tongue position (in mm.) between emphatic and nonemphatic [t] articulated in three environments: a natural word, nonsense disyllable, and [ʌtʌ] environments for Subjects 1 and 3.

contribute to differential perception of emphatic-nonemphatic consonants and their accompanying vowels.[1] Both C and V probably participate behaviorally and acoustically in emphatic production. The crucial change in pharyngeal cavity width is almost entirely a function of tongue movement and *not* of pharyngeal wall movement over lines E_3 through E_5 with the exception of [ḳ]. In all [ḳ] sequences examined, the velum approached and nearly approximated contact with the tongue during [ḳ] production. In other words, only for [ḳ] production is more than tongue movement alone involved in cavity constriction.

Effect of Context on Tongue Movement

Figure 5 shows that the greatest tongue movements for Subject 1 for [ṭ] vs. [t] in [ṭæbašir] vs. [tæbašir], occurs at reference line F_1. For the

[1] Preliminary results of a tape splicing study indicate that native Arabic listeners can detect the presence or absence of emphatic consonants as contrasted with nonemphatic cognates when they are spliced away from words.

nonsense syllable, maximum movement is at reference line E_3, and for the [ʌCʌ] utterance, it is at reference line E_5. Tongue movement is greatest for the nonsense syllable, 6.5 mm at E_3, lesser for the sustained [ʌCʌ] 5.4 mm at E_5, and least for the natural sequence, 5.0 mm at line F_1. For Subject 3 tongue movement is greatest at reference line E_5 for both sustained and natural production of the sounds, 9.0 mm, and only 6.0 mm at F_1 for the nonsense syllable. These two graphs show that for different subjects, different contexts show differential amounts and locations of tongue movements for each context. This is clear evidence that studies utilizing contrived nonsense utterances or sustained utterances, do not elicit the same articulatory responses which occur during production of natural speech.

Tongue Movement and Consonant Type

The over-all mean differences in tongue position for emphatic-nonemphatic consonant pairs are presented for Subjects 1 and 3 in Tables 3 and 4. In general, the tongue displacement patterns look alike. Subject 3 shows a more coherent, consistent, and less spread a pattern than does Subject 1. The maximum and minimum displacements for both subjects are located in in the same general places, except that there is generally much more displacement for Subject 3 at some points.

Tables 5 and 6 list the mean differences in tongue position for all vowels accompanying nonemphatic consonants. Differences are idiosyncratic within and between the subjects. There are obvious differences between the subjects in tongue position for vowels, particularly at reference line D where the mean difference is highest for the vowels accompanied by [ṣ] for Subject 1 and [ḳ] for Subject 3. The over-all tongue positions for the vowels in each context show much similarity between the two subjects, except for [ḅ] context which shows smallest movement for Subject 1, but not for Subject 3. In all cases, the vocal tract is constricted during the consonant, during the CV transition and during the vowel. Thus all three are articulatorily and acoustically involved in the emphatic backing movement.

For each emphatic-nonemphatic consonant pair the difference scores for each reference measurement line were averaged to give a gross estimate of over-all tract perturbation. The mean perturbation scores for consonants vary significantly within the subjects as well as between the subjects. For Subject 1, these scores are 5.08 mm, 2.89 mm, 2.76 mm, and 1.70 mm for [ḳ], [ṣ], [ṭ], and [ḅ] respectively. Accordingly,

Table 3. Mean (over-all vowels) tongue displacements along various reference lines for emphatic-nonemphatic consonant pairs interpreted in terms of vocal tract perturbation (Subject 1).

Con-sonants	Reference Measurements										Over-all Mean Difference
	D	E_1	E_2	E_3	E_4	E_5	F_1	F_2	F_3	F_4	
b	1.20	0.90	2.50	3.30	3.00	2.50	1.10	1.20	1.60	1.40	1.70
s	2.92	2.08	1.25	3.17	4.33	4.75	3.92	2.00	0.92	1.58	2.89
t	2.92	2.42	1.08	4.08	5.25	4.92	3.75	1.67	1.08	0.50	2.76
k	9.00	6.50	2.33	8.00	7.83	6.33	5.50	3.50	0.67	1.17	5.08

Differences in mm.

Table 4. Mean (over-all vowels) tongue displacements along various reference lines for emphatic-nonemphatic consonant pairs interpreted in terms of vocal tract perturbation (Subject 3).

Con-sonants sonants	Reference Measurements										Over-all Mean Difference
	D	E_1	E_2	E_3	E_4	E_5	F_1	F_2	F_3	F_4	
b	4.33	1.75	3.50	6.83	7.50	6.58	4.00	3.41	0.82	1.41	4.01
s	3.33	3.08	0.75	5.33	7.83	8.00	5.91	3.75	1.00	0.50	3.95
t	4.75	3.91	1.33	3.91	5.66	7.00	6.66	4.50	0.50	0.33	3.86
k	8.58	3.67	3.50	10.08	8.91	6.75	6.58	7.58	1.58	0.58	5.78

Differences in mm.

Table 5. Mean tongue displacements for vowels accompanying emphatic-nonemphatic consonants as a function of various reference lines interpreted as vocal tract perturbation for vowels (Subject 1).

Consonant Environ-ments	Reference Measurements										Over-all Mean Difference
	D	E_1	E_2	E_3	E_4	E_5	F_1	F_2	F_3	F_4	
b	1.00	0.70	1.30	1.10	0.90	0.90	1.10	1.20	0.70	0.60	0.95
s	2.92	3.50	2.58	2.67	3.25	3.25	2.58	1.50	0.91	1.00	2.17
t	2.58	1.73	1.58	1.67	2.67	3.08	2.75	1.67	0.83	1.25	1.98
k	2.17	4.00	3.17	0.83	1.83	2.33	2.33	3.33	3.00	0.17	2.32

Differences in mm.

Table 6. Mean tongue displacements for vowels accompanying emphatic-non-emphatic consonants as a function of various reference lines interpreted as vocal tract perturbation for vowels (Subject 3).

Consonant Environments	Reference Measurements										Over-all Mean Difference
	D	E_1	E_2	E_3	E_4	E_5	F_1	F_2	F_3	F_4	
b	3.33	2.58	3.83	3.17	3.41	4.25	4.75	4.58	1.00	0.75	3.17
s	2.58	1.91	1.17	3.58	4.08	4.66	3.25	1.08	2.17	0.50	2.50
t	2.91	1.50	1.83	2.35	3.66	3.08	3.08	2.50	1.17	0.41	2.25
k	4.25	4.33	3.75	1.00	2.83	3.50	4.08	3.25	2.33	0.41	2.97

Difference in mm.

mean perturbation of vocal tract width is greatest for [ḳ], nearly 5 times that observed for [ḅ] for Subject 1. Table 4 shows a small difference in the above order for Subject 3, wherein [ḅ] follows [ḳ] in size of perturbation. The backing gesture for [ḅ] can be very active, but [ḳ] demonstrates the most active tract constricting gesture of all.

For all vowels, [ḳ] consonant environment elicited most vocal tract perturbation. Table 5 shows the mean difference scores over all vowels for Subject 1. The over-all mean differences show almost the same hierarchical ordering of values as for consonants. Vowels in the [ḳ] environment for Subject 1 displayed most perturbation, 2.32 mm, and least for [b], namely 0.95 mm. For Subject 3, Tables 4 and 6, mean tract perturbations for consonants and vowels do not follow in exact order. In other words, the order of the over-all mean differences for Subject 1 for both consonants and vowels is [ḳ] > [ṣ] > [ṭ] > [ḅ]; for Subject 2 it is [ḳ] > [ḅ] > [ṣ] > [ṭ] for consonants and [ḅ] > [ḳ] > > [ṣ] > [ṭ] for vowels, although the [ḅ] and [ḳ] scores are not much different. Such results indicate that the vowels follow consonants in the amount of backing with the exception of [ḅ] for Subject 3. Hence, an unusual amount of coarticulation of emphaticness for [ḅ] has been observed. The covariance of the amount of vowel perturbation with consonant perturbation means that the "emphatic" feature is tied (in amount of backing) to specific consonants in such a way, that accompanying vowels show a like specificity of (coarticulated) perturbation.

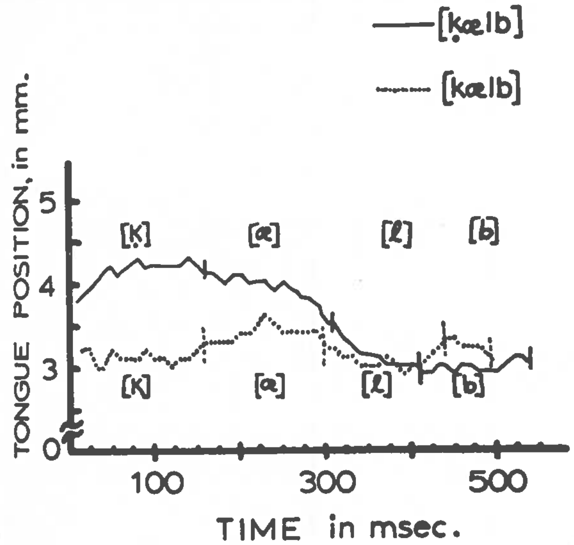

Fig. 6. Tongue position as measured along reference line E_4 (in mm.) during articulation of the words [ḳælb] vs. [kælb] for subject 2.

Tongue Movement in Natural Sequences

The words [ḳælb] vs. [kælb], and [ṭæbašir] vs. [tæbašir]

One can easily observe the large difference in tongue position between emphatic [ḳ] and nonemphatic [k] in Figure 6. This difference in tongue position slowly decreased in size throughout the vowel [æ] until the difference disappears during [l] and [b].

Similar results were obtained for the word [ṭæbašir] where C_1 is marked [+ emphatic] and the word [tæbašir] where C_1 is marked [− emphatic]. Figure 7 shows clearly that the backing gesture spreads, in a slowly decreasing fashion, over almost 3 1/2 segments of the word [ṭæbašir], ending midway through the vowel [a]. The spread of the feature [+ emphatic] over these segments must be deliberate LR coarticulation of backing across CVCV type syllables in contrast with a failure to spread completely across a CVCC# type (where # is final word boundary) as illustrated by the word [ḳælb], Figure 6. The spread of the backing gesture in the words shown in Figures 6 and 7 provide no evidence of a backing gesture spreading over an entire word, as was claimed by Firth 1964, and Mitchell 1956. The results for the word

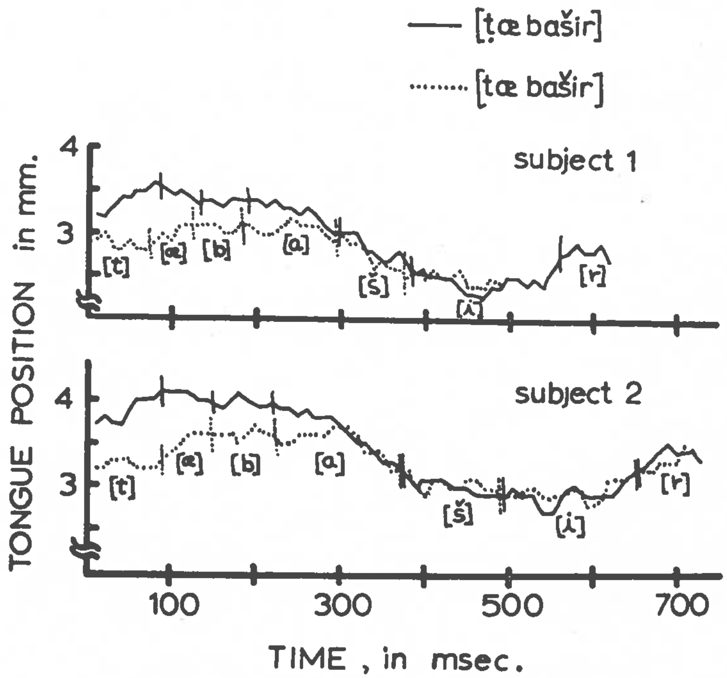

Fig. 7. Tongue position as measured along reference line E_4 during articulation of words [ṭæbašir] vs. [tæbašir] for Subjects 1 and 2.

[ṭæbašir] show clearly that the backing gesture can spread across two syllables and even an adjacent, nonemphatic consonant, [b], under certain conditions.

The words [ḳæṣ] vs. [ḳæs]

Figures 8 and 9 present data for the contrasting word [ḳæṣ] vs. [ḳæs]. In this case, the initial [ḳ]'s are noncontrasting, but the final [ṣ] vs. [s] are. In [ḳæṣ], there must be some RL, coarticulatory influence of [ṣ] upon [æ] because the backing on [æ] in [ḳæṣ] for line E_4, in particular, is greater than in [ḳæs]. The difference in amount of backing during the [æ] vowel appears at the starting point (first frame after consonant [ḳ] release) of this vowel, and increases steadily to a substantial value during [ṣ] for Subject 2. For Subject 1, this difference remains almost constant during articulation of [s].

Since there is little difference between the initial [ḳ]'s of [ḳæṣ] and

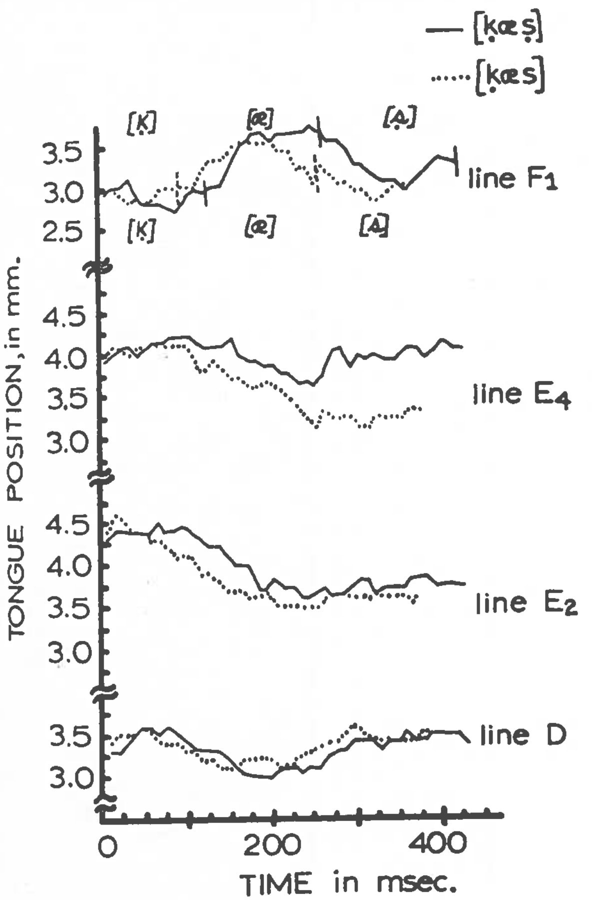

Fig. 8. Tongue position along various reference measure lines (in mm.) during production of the words [ḳæṣ] vs. [ḳæs] for Subject 1.

[ḳæs], a fact related to the "sameness" of the two sounds as being emphatic, the final [ṣ] must have little influence upon the initial [ḳ]. These data suggest that there are constraints on the lingual contour for both consonant and vowel productions when the feature [+ emphatic] is considered. Examination of Figures 8 and 9 along lines D, E_2, E_4 and F_1 indicates that the effect of emphaticness shows most clearly at certain positions along the tongue contour, in particular, reference line E_4 for Subject 1 and Subject 2; reference lines E_2 and F_1 show little difference, particularly E_2, for both subjects. Figure 9 shows

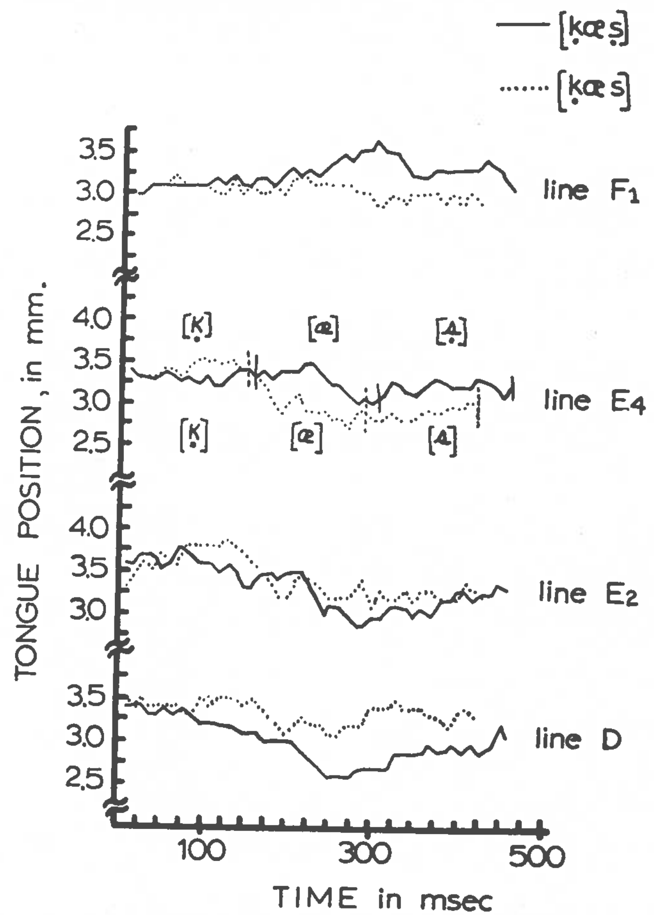

Fig. 9. Tongue position along various reference measure lines (in mm.) during articulation of the words [ḳæṣ] vs. [ḳæs] for Subject 2.

that the difference increases to a large value for the measure E_4 and decreases to a small value along line F_1 for Subject 2. Other measures show lesser or nonexistent significant difference between emphatic and nonemphatic effects. Subject 1 shows a coarticulation of tongue depression along line D which nicely fits the coarticulation of tongue backing along line E_4.

Figure 10 shows the effect of medial emphatic [ṣ] on the following vowel [I] in [ḳæṣIr] vs. [ḳæsIr] where the evidence of spread of backing

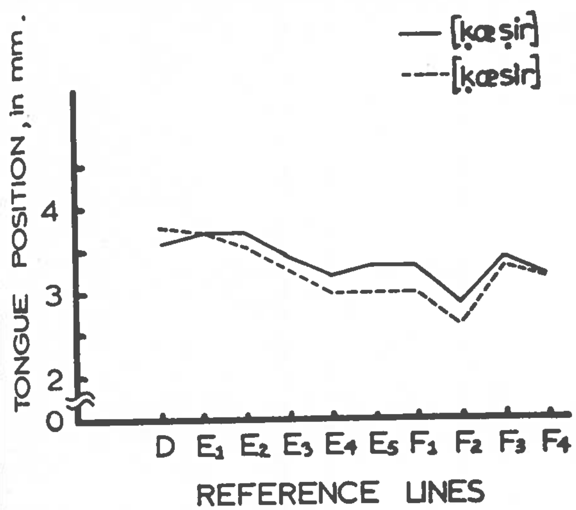

Fig. 10. Tongue position as measured along various reference measure lines (in mm.) for one frame from the center of the vowel [I] in two different words, [ḳæṣIr], vs. [ḳæsIr] for Subject 1.

gesture to V_2 is very obvious, particularly at the reference lines E_4, E_5, and F_1. In this case there is a strong support of left to right (LR) coarticulatory spread of backing from [ṣ] to V_2.

Other Measures of Emphatic-Nonemphatic Differences

An examination of syllable durations indicated that there is only a slight difference between emphatic and nonemphatic sounds in natural words. In Figure 6 the word with emphatic [ḳ] is 50 msec longer in duration than the word with nonemphatic [k]. Similarly, in Figures 8 and 9 there are differences of 10 msec depending on the subject and the number of segments in the words. Note that in Figure 7 the over-all difference is small, 10 msec, possibly because the initial emphatic [ṭ], is only one of seven segments in the word [ṭæbašir].

Discussion

General Findings

The data of this study indicate that the tongue dorsum and/or tongue root (that portion of tongue between lines E_1 and F_1 in Figure 1) is the primary articulator for emphatic sound production. Viewed saggitally, the lingual profile exhibits simultaneous depression of the palatine dorsum and reaward movement of the pharyngeal dorsum during articulation of emphatic sounds; all emphatic consonant cognates examined in this study displayed this differential tongue movement. The net physiological result of this differential movement is a marked, localized pharyngeal constriction and a simultaneous, slight expansion of the oral cavity in front of this constriction. The segment of the tongue dorsum which moves furthest, and most actively and consistently for all subjects is located at about the position of E_4.

These results indicate that the posterior pharyngeal wall and the velum *are not* actively involved in the differential articulation of emphatic vs. nonemphatic sounds, except for [ḳ] where the velum lowers, approaching and even contacting the palatine dorsum. The posterior pharyngeal wall contributes little or nothing to emphatic consonant production in terms of observable movement. The crucial changes in pharyngeal cavity width result almost entirely from tongue dorsum-root movements in an anterior-posterior line. No other differential changes in articulator velocity, duration of movement or closure, or of timing were observed between emphatic cognate consonants. Nor did the hyoid bone and associated structures display differential movement between the cognate sounds. It is obvious that the traditionally used terms, namely velarization, pharyngealization, and laryngealization for Arabic emphatic sounds are inappropriate to describe the events occurring during emphatic-nonemphatic sound production.

The CV and VC sequences examined in this study were not restricted to nonsense syllabic structures, but efforts were made to have the investigation include natural sequences (actual words). The data for real words show that there are significant differences in the location, amount of, and spread of the backing gesture between natural and nonsense sequences (see Figure 5). Thus, although it is convenient to use nonsense syllables/words so that phonetic construction can be easily and systematically varied, the resulting articulations differ, sometimes markedly, from like articulations seen in meaningful words. Whatever the cause of the differences—semantics, familiarity, prosody—they are real, and force a limit on generalization from nonsense item articulation behavior to contextual speech.

Coarticulation of the Emphatic Gesture

This study confirms that emphatic consonants spread, or induce a 'backing,' constricting gesture of the tongue in surrounding vowels and consonants. Studies of articulator behavior, Kozhevnikov and Christovich (1966), Daniloff and Moll (1968), McNeilage and DeClerk (1969) and Öhman (1966), have shown that phonetic context dictates the variability of articulatory gestures as well as the spread of such gestures across neighboring segments. In addition to phonetic context, coarticulation (and concomitant allophonic variation) is a function of the anatomical construction and neuro-mechanical time behavior of the articulators involved.

The source of the coarticulation observed in this study can not be attributed solely to mechano-inertial factors or to phonetic context. The subjects spoke slowly enough to permit the tongue to return to an "unbacked" position for following segments using ÇV and, the backing gesture was easily fast enough to begin at the start of the emphatic consonant and not on the preceding vowel in VÇ. Yet, overlap of backing to vowels in LR and RL directions, and even over adjacent syllables was encountered. This leads to the conclusion that the neural command(s) responsible for the backing gesture of emphatic sounds are centrally programmed at a very high level, with an integrity and strength of occurrence as strong as those for voicing or nasal emission, etc.

It was observed that the 'backing-constriction' tongue movement coarticulates rather freely from consonants to vowels. The muscle systems involved in this maintain their activity throughout both vowels and emphatic consonants. Hence, this gesture is not contradictory to vowel production in much the same way that a velum lowering gesture appropriate for [n] is not contradictory to vowel production in English words like "freon," Moll and Daniloff (1971). The backing gesture probably results from the simultaneous activity of the genioglossus, the styloglossus, and the hyoglossus muscles. The genioglossus is attached to the interior margins of the mandible and functions to push the tongue body forward and/or depress the tongue tip. The styloglossus pulls the tongue upwards and backwards with the agonistic aid of the palatoglossus. The hyoglossus muscle is capable of pulling the tongue mass backwards and downwards, and is probably the major agent in decreasing the cross-sectional area of the pharyngeal cavity (see Lindblom and Sundberg 1969, pp. 17—18, and Cunningham, Vol. 3, 1961, pp. 316—317).

Direction and Extent of Coarticulation

The data show that coarticulations of the backing gesture occurs freely in RL and LR directions over the vowel in C̣V and VC̣ syllabic constructions.

Previous investigators, Perkell (1969), and Carney and Moll (1969), observed RL effects for tongue dorsum movements in CV syllables. Amerman (1970) extended these results to show RL effects for tongue dorsum in C_1C_2V, for tongue tip in VC_1C_2. Thus, the tongue can easily, 'anticipate', in an RL fashion, articulatory shapes and positions two segments in advance of when they are actually assumed. And, these tongue dorsum positions can be retained, carried over in a LR fashion from vowel to consonant in VCC units. Amerman's results for English speakers show that both backing (for back vowels) and fronting (for front vowels) can occur widely in CCV, though in these cases, it is the vowel which dictates the movements. For emphatic sound production, the consonant induces backing, VC̣ or C̣V, of the tongue dorsum. The LR spread of backing in emphatic production is *very large* (larger than RL spread) and greater in extent, up to three segments in [ṭæbašir], than RL effects. Evidently the speaker deliberately wills (programs) the LR spread of backing, probably because the emphatic-nonemphatic contrast is much stronger and more distinct, when LR spread carries the feature to many segments. This is in contrast to MacNeilage and DeClerk (1969) and Amerman (1970) who found only small LR effects for tongue movement.

Specific detail of RL and LR effects for the tongue dorsum can be seen in Figures 6, 7, 8, and 9. For [ḳæṣ] vs. [ḳæs], figures 8 and 9, both [ḳ]'s are marked [+ emphatic]; and differences in the [æ]'s of the two words must be related to the dissimilar [ṣ] vs. [s], that is, to the word final C_2 of [ḳæṣ]. In other words, the differences in the backing gesture observed for [æ] in Figures 8 and 9, are clear evidence of RL coarticulation of emphaticness from consonant$_2$ (C_2) to the vowel [æ].

Figure 6 provides a clear example of LR carry over of the emphatic backing gesture from C_1 to V in a $C_1VC_2C_3$ type syllable. This failure to show spread of backing over the entire monosyllabic word may result from the word final position of the consonants (in no real word did backing spread entirely across the word). It might also be that liquid [l] production is 'contradictory' to the backing gesture—perhaps frontal X-rays would show a constrictory movement of the lateral pharyngeal walls for [l]. Data for the words [ḳælb] vs. [kælb] in Figure 6 indicate that coarticulation of emphaticness affects only the neighboring vowels in C̣VC type mono-syllabic words. In the C̣VC̣V nonsense di-syllables, the backing spread over the final vowel; if CVCV can be considered a nonsense-word, then in a crude sense, an entire word can be emphaticized if it consists solely of open syllables. These emphatic consonant effects contradict Öhman's notion that vowel gestures are most influential factor in coarticulation. Such a contradiction may occur only for emphatic backing gestures in Arabic. Further research in other languages such as Russian may serve to confirm this.

Syllabic spread of backing gestures. Coarticulation in the tri-syllabic words, [ṭæbašir]—[tæbašir], was particularly interesting because backing spread from C̣$_1$ across $V_1C_2V_2$, a distance of two syllables in LR direction for both subjects (see Figure 7). In this case the LR backing gesture moved across the open syllable boundary. Once again, however, the entire word was *not* emphaticized.

It would seem that the emphatic backing gesture only spreads over a certain number of (open) syllables in multi-syllabic words, but fails to spread fully over a mono-syllabic word of CVCC type; however, it does spread entirely over a nonsense C̣VC̣V di-syllable constructed of open syllables. These results lead one to conclude that coarticulation of the backing gesture is not a function of C or V alone, but is a syllable-tied process. This is confirmed by the sequence $C_1V_1C_2V_2C_3V_3C_4$, [ṭæbašir], where C_1 is specified [+ emphatic], the emphatic backing gesture was observed on $C_1V_1C_2V_2$, but not on any segments of the final syllable.

Concluding Remarks and Consideration of Future Research

To conclude, despite individual differences, and less than ideal measuring systems of reference lines, the major physiological-articulatory and acoustic cue in every emphatic-nonemphatic pair is the vocal tract constriction gesture. Two lingual articulators were observed to participate in the emphatic backing gesture; namely the palatine dorsum and the pharyngeal dorsum. Their movements provide direct evidence of the existence of VC and CV, coarticulatory syllabic types in terms of LR and RL spread of emphaticness. Indeed, the spread of constriction to the vowel in C̣V or VC̣ type units is direct evidence of coarticulation of emphatic backing articulatory gesture from consonant to vowel.

Summary

The aim of this study was to investigate differential articulatory movements involved in emphatic-nonemphatic cognate consonant production in Arabic. The consonant sounds, [b, s, t, k] and their emphatic counterparts [ḅ, ṣ, ṭ, ḳ] were combined with the vowels [i, u, a] and their short counterparts [I, U, æ] in natural and nonsense sequences. The natural sequences were actual words of CVC, CVCC, CVCVC, and CVCVCV types; the nonsense words were of CVCV type. High speed, lateral cinefluorographic films were made for three speakers of Baghdad Arabic dialect at a rate of 100 frames per second. Measurements of the activities of the dorsum and the root of tongue, the velum, the hyoid bone, and the posterior pharyngeal wall were made from the tracings along a series of reference lines. These measurements were then contrasted for emphatic-nonemphatic cognate pairs of consonants as well as for their accompanying vowels.

It was found that the main active articulator involved in the differences observed between emphatic-nonemphatic cognates was the tongue. During emphatic sound production the palatine dorsum moved inferiorly and the pharyngeal dorsum moved toward the posterior pharyngeal wall. No other emphatic-nonemphatic differential articulatory gesture was observed except for velum lowering for [ḳ].

The results confirmed that RL and LR coarticulation of the backing gesture for 'emphatic' sounds occurred in real and nonsense words; backing spread from the emphatic consonant to surrounding vowels and even syllables, but never over a whole word.

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