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Articles

ACOUSTIC CHARACTERISTICS OF
ARABIC PHARYNGEAL AND PHARYNGEALIZED CONSONANTS

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Abstract: Spectrographic data were examined in order to find an acoustic correlate for the classification of "emphatic" in traditional Arabic phonology. It was found that an emphatic consonant affects the steady state and transition of a preceding or following consonant. The upper pharyngeal/lower pharyngeal pairs were found to resemble nonemphatic/emphatic pairs.

The phonology of Modern Standard Arabic includes nine consonants with pharyngeal constriction in their articulation; in the production of these consonants, the root of the tongue approaches the pharyngeal wall. These sounds (as well as similar sounds which occur in the different dialects of colloquial Arabic) and their effect on surrounding sounds, give Arabic its characteristic "throaty" or "guttural" sound. Included in the sounds with pharyngeal constriction are those sounds known as "emphatics", the pharyngeal fricatives (or approximants) and the velar and uvular fricatives.

In traditional Arabic phonology, certain consonants are classified as "mufaxxam" (heavy); in English, these have been called "emphatic" consonants. This study attempts to find an acoustic correlate for the "emphatic" classification by comparing some acoustic features of non-emphatic/emphatic consonant pairs and of vowels adjacent to them. The non-emphatic/emphatic pairs examined are:

/s/ voiceless dental sibilant
/ṣ/ voiceless post-dental sibilant, pharyngealized
/t/ voiceless dental stop
/ṭ/ voiceless post-dental stop, pharyngealized
/d/ voiced dental stop
/ḍ/ voiced post-dental stop, pharyngealized
/ð/ voiced inter-dental fricative
/ð̣/ voiced post-interdental fricative, pharyngealized
/k/ voiceless velar stop
/q/ voiceless uvular stop

The above description is that of Al-Ani and Shammas in The Phonology and Script of Literary Arabic (1971), with the term "pharyngealized" replacing their use of "velarized" in the description of the first four pairs. The emphatic members of these pairs, characterized by backing of the primary articulation and secondary pharyngeal constriction, have

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commonly been called "velarized" or "velarization" consonants. X-ray studies, however, show the secondary articulation to occur in the pharyngeal region, with the root of the tongue approaching the pharyngeal wall (Al-Ani 1970). The emphatic member of the fifth pair, /q/, also has a primary articulation farther back than that of its non-emphatic counterpart, and a secondary pharyngeal constriction. Delattre's 1971 X-ray study of the production of /q/ showed that simultaneous with closure, in which the back of the tongue meets the uvula, the root of the tongue approaches the pharyngeal wall. In addition to pharyngeal constriction, the emphatic members of each pair have in common the phonological effect of backing the long and short low vowels of Arabic.

The other consonants which are characterized by pharyngeal constriction are:

/x/ voiceless velar fricative[1]
/ħ/ voiceless pharyngeal fricative
/R/ voiced uvular fricative
/ʕ/ voiced pharyngeal fricative[2]

(Al-Ani and Shammas 1971)

Delattre found /x/, /ħ/, /R/ and /ʕ/, as well as /q/, to be cases of pharyngeal articulation, "in which the root of the tongue assumes the shape of a bulge and is drawn toward the vertical back wall of the pharynx to form a stricture." (Delattre 1971, p.137) According to Delattre, in the cases of /ħ/ and /ʕ/, the stricture between the tongue bulge and the pharyngeal wall is lower than that of /a/. In the cases of /q/, /x/ and /R/, the stricture is higher than that of /a/, near the middle of the pharyngeal wall. /R/ and /x/ are characterized by a circular movement, the stricture rising along the pharyngeal wall. In the case of /R/, the uvula curls into a trill position, while in the case of /x/ the uvula lies flat over the tongue bulge, prolonging the stricture where friction is produced. In the production of /R/, a trill is not always produced, and when one is, there appear to be intermittent reductions in intensity, rather than interruptions of the air stream.

Delattre considers the consonants above to be non-emphatic/emphatic pairs; the second member of each pair is more backed than the first. Other scholars consider it possible that there are emphatics besides those given in the first list of consonants above, but do not agree as to which consonants they are nor as to what their non-emphatic counterparts are (Jakobson 1957, p.110). This study will compare these pairs, the upper pharyngeals and the lower pharyngeals, respectively, with those pairs agreed to be non-emphatic/emphatic.

The consonants listed above have been studied by various researchers in articulatory phonetics and acoustic phonetics. Ali and Daniloff (1974) found that speakers of Baghdad Arabic were able to identify the presence of pharyngealized consonants (in a forced choice between the non-pharyngealized or pharyngealized member of a pair) even when tape-splicing had removed the consonant from a word. Their subjects were able to identify pharyngealization co-articulated in forward and backward directions. As they removed the CV or VC transitions as well as the consonant in their splicing operation, their results indicate the presence of some perceptual cue of pharyngealization in the steady state of the adjacent vowel.

Obrecht (1970) studied the effects of variation in burst frequency and F2 and F3 onset frequency in the perception of /t/, /ṭ/, /k/, and /q/ followed by /a/ (subjects were offered a forced choice between all four stops) in a syllable produced by a pattern playback synthesizer. F3 onset frequency appeared to be an ineffective cue, while burst frequency appeared to be the most effective. F2 onset frequency was also effective, more so in the cases of discrimination of /q/ versus /k/ and /q/ versus /t/ or /ṭ/ than in the case of /t/ versus /ṭ/.

In an earlier study, Obrecht (1960) systematically varied F2 onset frequency in otherwise identical syllables produced by pattern playback synthesis, offering subjects a forced choice between pharyngealized and non-pharyngealized members of such pairs in Lebanese Arabic. An interesting finding of his preliminary experimentation with synthesis is that the Arabic pharyngealized consonants required an F2 transition of longer duration in order to be acceptable to the informants than was previously found to be optimal for the synthesis of English consonants (70 msecs rather than 50 msecs). This presumably is due to the additionalarticulatory movement of the tongue root, a rather slow-moving articulator.

In his preliminary work, Obrecht examined the proportionate importance of F2 onset frequency and vowel steady state quality in signalling the presence of pharyngealization. He found /aa/, the long low back vowel, to be substantially changed throughout when following a pharyngealized consonant in real speech; F2 was lower throughout the duration of the vowel. The backed allophone of /aa/ when synthesized with F2 onset frequency in the non-pharyngealized range consistently yielded pharyngealized identifications; similarly, the front allophone of /aa/ yielded non-pharyngealized identifications when synthesized with F2 onset frequency in the pharyngealized range. The informant was dissatisfied with the quality of samples so synthesized. Thus it appears that in the case of /aa/, steady state quality is a morepowerful cue than that of F2 onset frequency, but F2 onset frequency appears to contribute to the perception of the sound. For this reason, Obrecht synthesized a neutral centralized mid vowel, not occurring in Arabic, in order to test the effects of varying F2 onset frequency. Although Obrecht at one point mentions a somewhat lowered allophone of /ii/ near pharyngealized consonants, he found that /ii/ has a "relatively standard" steady state F2 regardless of preceding pharyngealization. Because of the high F2 of /ii/, the main cue of pharyngealization is an extreme transitional movement from the low F2 onset inherent in emphatic consonants. In his synthesis experiments, he found variation of the steady state F2 of /ii/ to have little effect. /uu/ also displayed a "relatively standard" steady state regardless of pharyngealization, without notable transitional formant movement, due to the inherent low F2 of /uu/.

Obrecht concluded from his study that F2 onset was the "overwhelming cue" to the non-pharyngealized/pharyngealized distinction. The F2 onset zone indicating pharyngealization to the hearers of his synthetic syllables was 1000-1400 cps; at 1450 cps identification was random.

In a review of Obrecht's study, William S-Y Wang called Obrecht's conclusion overdrawn. He suggested that further study be made of F0, F1, and the durational characteristics of elements of pharyngealized syllables, as well as F2 and F2 onset, in real speech, in order to determine the most important parameter.

In Delattre's study of pharyngeal consonants (1971), he made certain predicitions of acoustic features from X-ray studies of articulation, which he confirmed by analysis of spectrograms and speech synthesis. Consistent with the articulatory descriptions given earlier, the first formant for /ʕ/ and /ħ/ should be higher than that of /a/, and the second formant approximately the same as that of /a/. When they are both adjacent to /u/, coarticulation should lower the level of both formants; adjacent to /i/, the first formant should be lowered and the second raised. He also predicted the lowering of the third formant transition, due to the double-bulged tongue shape of /ʕ/ and /ħ/, which resembles that of the American /r/.

/R/, /x/ and /q/, with a pharyngeal constriction higher than that of /a/, should have a lower F1 (onset around 550 cps). Delattre contends that the perception of /x/ and /R/ depends less on the friction noise produced than on the sound of the formant transitions which result from changes in the volume of the pharyngeal and mouth cavities as the tongue moves toward and away from the pharyngeal wall.

Klatt and Stevens (1969) also made predictions of the acoustic features of pharyngeal consonants, which they confirmed by analysis of spectrograms. Their results agree with those of Delattre. They found the pharyngeal consonants to be characterized by a high F1, and found /ʕ/ and /ħ/ to be distinguished from /x/, /R/ and /q/ by a lower F3. They found little evidence of friction noise in the spectrograms of voiced fricatives. In the case of /R/, this agrees with Delattre's claim that formant transitions are a more important cue than friction noise in the perception of /R/.

From the above studies, one would expect to find a lowered F2 either in the steady state of a vowel in the environment of a pharyngealized consonant or at the onset or terminus of the vowel (the point immediately adjacent to the consonant). In the case of the pharyngeal pairs, one expects a higher F1 in a vowel in the environment of the lower members, /ʕ/ and /ħ/. As F2-F1 frequency correlates with the degree of backness of articulation, according to Ladefoged, one might expect the second (lower) member of each pair to cause a lower F2-F1 in adjacent vowels.

Procedure

A set of minimal pairs was chosen in which each member of all the consonant pairs occurred preceding and following each long vowel of Arabic. The 84 words, listed in the appendix, were inserted in the frame sentence: /qaalat _____ marratan uuxra/, 'she said _____ again'. Each sentence was read three times serially by the informant, a Saudi Arabian, who attempted to use consistently "classical" pronunciation. The informant paused slightly before and after the inserted word.

The sentences were recorded in a sound-treated room of the KU Language Laboratory. A wide-band and a narrow-band spectrogram were made of each sentence, using the second example read by the informant, on a Kay Elemetrics Co. 6061B sonagraph.

Measurements were made of:

- fundamental frequency of vowel
- duration of consonant (where measurable)
- duration of burst
- frequency of bands of energy in continuant consonants
- frequency of bands of energy in bursts
- F1, F2, F3 frequency of vowel at onset and terminus
- F1, F2, F3 frequency of vowel at steady state

Description of the Phonemes

/aa/: long low back vowel, following or preceding /ṭ, ḍ, ṣ, ð̣, q, x, R, r/

/aa/: long low front vowel, in other environments

Formant frequencies in the words examined may be seen in Table I.

Average steady state formant frequencies:

back vowel, in the environments given above		front vowel, in other environments	
F1	672	F1	710
F2	1197	F2	1530
F3	2336	F3	2345
F2-F1	525	F2-F1	820

The emphatic member of each non-emphatic/emphatic pair determines *that a following or preceding long low vowel is back; the upper pharyn-*geals have the same effect. Backing is visible in the lower F2 and resulting lower F2-F1 of the vowel in the environment of these consonants.

According to Al-Ani (1970), /r/ is a voiced dental trill which is pharyngealized when it occurs next to pharyngeal consonants and in the environment of /a/ or /aa/.[3] The backing effect of /r/ on an adjacent /aa/ is clearly visible in the words used in theis study; in the case of /saar/, even the initial /s/ appears to be somewhat pharyngealized by anticipatory coarticulation.

/ii/: long high front vowel
See Table II for formant frequencies in the words examined.
Average steady state formant frequencies:

F1	391
F2	2180
F3	2641

The steady state of /ii/ remains relatively constant regardless of adjacent consonant. /ii/ in the environment of an emphatic consonant is marked by a steep F2 transition. F2 onset or terminus adjacent to an emphatic is much lower than steady state F2 and much lower than F2 adjacent to the non-emphatic counterpart. (See Table IV for onset and terminal F2 frequencies.)

Range of onset and terminal F2 frequencies:

	emphatic	non-emphatic
onset	1250-1850	2000-2100
terminus	1100-1550	2000-2200

F2 is somewhat lower adjacent to the lower pharyngeal /ʕ/ than at steady state. F2 adjacent to the upper pharyngeal counterpart, /R/, is even lower; the upper pharyngeal shows a steeper F2 transition. /ii/ adjacent to the lower pharyngeal /ħ/ shows no F2 transition. /ii/ before the upper pharyngeal /R/ shows some F2 transition due to a somewhat lowered F2 terminus. In both cases of /x/ in the environment of /ii/, the band of energy found in the friction of the consonant which joins F2 of /ii/ has a steep slope.

/uu/: long high back vowel
See Table III for the formant frequencies in the words examined.
Average steady state formant frequencies:

F1	378
F2	812
F3	2317

The steady state of /uu/ remains relatively constant regardless of the consonant adjacent. In every case but one, F2-F1 adjacent to an emphatic consonant is lower than that adjacent to the non-emphatic counterpart. *In the exceptional case (/fuuk/, /fuuq/)*, F2-F1 is the same at the terminus in both words, although energy in the aspiration following the release of the consonants may indicate a higher F2 locus for /k/ than for /q/ (there is energy at 1400 cps in the aspiration of /k/, and at 1000 cps in the aspiration of /q/).

In the case of the upper/lower pharyngeal pairs, the lower pharyngeal pairs, the lower pharyngeals show F2 transition, F2 being higher adjacent to the consonant, while the upper pharyngeals do not. The band of energy in the lower pharyngeals which joins F2 of /uu/ is higher than the corresponding band in the energy of the upper pharyngeals.

/t/: voiceless aspirated dental stop

In measurable (final) position, the duration of closure ranges from 86 msecs to 100 msecs. The burst is strongly aspirated, initially and finally; duration of release plus aspiration ranges from 44 to 84 msecs. (Table V gives durations; Table VII gives the frequency of energy visible in the burst and aspiration.)

F1 onset	300-500	F1 terminus	350-750
F2 onset	900-2200	F2 terminus	1450-2200

/ṭ/: voiceless unaspirated post-dental stop, pharyngealized

In final position, the duration of closure ranges from 100 msecs to 114 msecs; the duration of the burst in initial and final position ranges from 2 msecs to 24 msecs. The longest burst is slightly aspirated, occuring in word-final position. (See Table V for durations; see Table VII for the frequency of energy visible in the burst.)

F1 onset	400-500	F1 terminus	400-700
F2 onset	800-1250	F2 terminus	1100-1300

/d/: voiced dental stop

Duration of closure ranges from 80 msecs to 156 msecs. Duration of the burst ranges from 10 msecs to 26 msecs. (See Table V for durations; see Table VIII for frequency of energy visible in the burst.) In final position, /d/ is devoiced and lightly aspirated.

F1 onset	400-500	F1 terminus	350-500
F2 onset	850-2000	F2 terminus	700-2100

/ḍ/: voiced post-dental stop, pharyngealized

Duration of closure ranges from 60 msecs to 120 msecs; the duration of the burst is 10 msecs or less. (See Table V for durations and Table VIII for the frequency of energy in the burst.)

F1 onset	350-500	F1 terminus	350-600
F2 onset	700-1300	F2 terminus	700-1300

/s/: voiceless dental fricative

The duration ranges from 140 msecs to 210 msecs. In all cases but one, that of /saar/, friction begins above 1600 cps. In the case of /saar/, the slight band of friction at 1250 cps indicates pharyngealization of the /s/ by the following back vowel and /r/. (See Table VI for duration and Table IX for frequency of energy in the friction.)

F1 onset	350-600	F1 terminus	350-500
F2 onset	1250-2000	F2 terminus	1300-2400

/ṣ/: voiceless post-dental fricative, pharyngealized

Duration ranges from 144 msecs to 204 msecs. In every case, within the friction of the consonant there is a band of energy at 1250 cps or 1300 cps, which joins F2 of the vowel. (See Table VI for duration and Table IX for the frequency of energy in the friction.)

F1 onset	300-600	F1 terminus	350-500
F2 onset	1000-1700	F2 terminus	1000-1550

/ð/: voiced interdental fricative

Duration ranges from 96 msecs to 196 msecs. In initial position, light bands of energy at the level of the vowel formants and light energy above 3000 cps are seen only in the final portion of the consonant. In final position, /ð/ is partially devoiced and the energy which is visible appears immediately after the vowel. There is a slight release at the end. (See Table VI for durations and Table X for the energy visible in the consonant.)

F1 onset	300-700	F1 terminus	300-800
F2 onset	800-2200	F2 terminus	800-2000

/ð̣/: voiced post-interdental fricative, pharyngealized

Duration ranges from 80 msecs to 192 msecs. In initial position, light bands of energy at the level of the vowel formants and light energy above 2500 cps are seen only in the final portion of the consonant. In final position, /ð̣/ is devoiced, shows light energy at the level of the vowel formants, and has a lightly aspirated release. (See Table VI for durations and Table X for the energy visible in the consonant.)

F1 onset	350-700	F1 terminus	400-750
F2 onset	800-1600	F2 terminus	800-1250

/k/: voiceless aspirated velar stop

In measurable (medial and final) positions, the duration of closure ranges from 82 msecs to 96 msecs; the duration of aspiration ranges from 54 msecs to 104 msecs. (See Table V for durations and Table XI for the frequency of energy visible in the burst and aspiration.

F1 onset	450	F1 terminus	400-500
F2 onset	800-2100	F2 terminus	850-2200

/q/: voiceless unaspirated uvular stop

In measurable (medial and final) positions, the duration of closure ranges from 94 msecs to 104 msecs. The duration of the burst (and any aspiration) ranges from 10 msecs to 70 msecs; /q/ is lightly aspirated in word-final position. (See Table V for durations and Table XI for the frequency of energy visible in the burst.)

F1 onset	450	F1 terminus	400-750
F2 onset	800-1850	F2 terminus	850-1500

/x/: voiceless velar fricative

Duration ranges from 160 msecs to 340 msecs. When /x/ is found in the environment of /aa/ and /ii/, the lowest band in the friction is found from 1200 cps to 1500 cps; this band joins F2 of the vowel. When /x/ is before /ii/, the band within the friction rises to the level of the high vowel F2; when /x/ is after /ii/, F2 of the vowel has a falling transition and the band within the friction drops as well. When /x/ is in the environment of /uu/, the lowest band in the friction is at the level of F2 of /uu/. Friction continues to the top of the display in every case. (See Table VI for durations and Table XII for the frequency of areas of energy within the friction.)

F1 onset	250-750	F1 terminus	250-750
F2 onset	800-2200	F2 terminus	750-2000

/ħ/: voiceless pharyngeal fricative

Duration ranges from 180 msecs to 230 msecs. When /h/ is in the environment of /aa/ and /uu/, there is a band of energy in the friction found from 1250 cps to 1400 cps, which joins F2 of the vowel. In the environment of /uu/, this band slopes, due to the low F2 of /uu/. In the environment of /ii/, the lowest band of energy, which joins F2 of /ii/, is slightly lower than the vowel F2. Most friction occurs below 4500 cps; some light friction occurs above. (See Table VI for durations and Table XII for the areas of energy within the friction.)

F1 onset	300-800	F1 terminus	250-750
F2 onset	800-2250	F2 terminus	800-2200

/R/: voiced uvular fricative

Duration ranges from 100 msecs to 180 msecs. In medial and final positions, /R/ is devoiced and contains little energy. A trill is indicated by periodic reductions in the intensity of the energy of the consonant. In the environment of /aa/ and /ii/, /R/ contains a band of energy around 1100-1500 cps, which joins F2 of the vowel. F2 of /ii/ slopes between the high steady state F2 and the level of the band; the band of energy itself slopes somewhat as well. There is some friction from 3000 cps to the top of the display. (See Table VI for durations and Table XII for the frequency of energy in the fricative.)

F1 onset	350-600	F1 terminus	450-600
F2 onset	750-1450	F2 terminus	750-1550

/ʕ/: voiced pharyngeal fricative

Duration ranges from 96 msecs to 240 msecs. /ʕ/ appears very much like a vowel; the bands of energy resemble vowel formants. In the environment of /aa/ and /uu/, /ʕ/ has a band of energy around 1000 cps to 1300 cps which joins F2 of the vowel; this band slopes in the environment of /uu/, due to the low F2 of the vowel. The band joining F2 of /ii/ is higher (1800 cps and 1600 cps), and slopes somewhat, due to the high F2 of /ii/. Little energy is visible apart from the formant-like bands. The lack of friction in the consonant and the formant-like appearance of the bands of energy suggest that /ʕ/ is actually an approximant rather than a fricative. (See Table VI for duration and Table XIII for the frequency of energy within the consonant.)

F1 onset	350-800	F1 terminus	450-600
F2 onset	750-1450	F2 terminus	850-1850

Conclusion

In the case of the non-emphatic/emphatic pairs, the effects of the consonants on the vowels are consistent with Obrecht's findings concerning F2 onset and steady state variation in his experiments with synthesis. This study also showed that an emphatic consonant following the vowel has the same effects on vowel steady state and vowel transition as an emphatic consonant preceding the vowel.

The steady state of the low vowel /aa/ is farther back in the environment of the emphatic than in that of the non-emphatic counterpart; the backness is seen in the lower F2-F1. F2 of /aa/ is lower immediately adjacent (at vowel onset and terminus) to an emphatic consonant than the non-emphatic counterpart; the reduction of F2-F1 caused by the backing influence of the emphatic is greater adjacent to the consonant than at steady state. The F2 onset and terminus frequences of /aa/ in the cases of emphatic consonants were within the 1000-1400 cps range for vowel onset that Obrecht found to yield pharyngealized identifications of synthetic syllables; F2 onset and terminus frequencies in the cases of non-emphatic consonants were above this range. (See Table IV: Onset and terminal F2 transition frequencies.)

The steady state of /ii/ is similar in all cases. F2 of /ii/ in the environment of each emphatic member of a pair is characterized by the steep transition noted by earlier researchers. In every case, F2-F1 of /ii/ adjacent to an emphatic is considerably lower than that adjacent to the non-emphatic counterpart. Although F2 onset and terminus frequencies are lower adjacent to the emphatic member of each pair, in several instances thay are higher than Obrecht's 1000-1400 cps range for pharyngealization.

The steady state of /uu/ is also similar in all cases. F2-F1 at onset or terminus was somewhat lower for the emphatic than the non-emphatic member of each pair, except in the case of /fuuk/, /fuuq/ mentioned above. Due to the inherent low F2 of /uu/, F2-F1 onset and terminus values are low in every case, and the difference between F2 onset and terminus values of the members of a pair is small. F2 of /uu/ adjacent to the emphatic consonant was usually lower than Obrecht's 1000-1400 cps range for pharyngealized identifications, while F2 of /uu/ adjacent to the non-emphatic /s/ was within that range.

Neither duration of the consonant nor fundamental frequency of the vowel appeared to be significant in distinguishing emphatic consonants from their non-emphatic counterparts. In the case of stops, the burst (plus aspiration of the voiceless consonants) appeared to distinguish the two. The non-emphatic voiceless stops, /t/ and /k/, are aspirated, while the emphatic counterparts, /ṭ/ and /q/, are unaspirated in initial and only lightly aspirated in final position. The non-emphatic voiced stop, /d/, has a burst of longer duration than that of /ḍ/. When a band of energy appears in the burst of an emphatic consonant near the level of F2 onset or terminus, it is lower than the corresponding band in the burst of the non-emphatic counterpart.

In the case of the sibilant pair, the friction of the emphatic /ṣ/ contains a band of energy (1250-1300 cps) joining F2 of the vowel, which is lower than the corresponding band in the friction of non-emphatic /s/. (The light band at 1250 cps in /s/ of /saar/, as noted above, indicates pharyngealization due to anticipatory coarticulation.) /ð/ and /ð̣/ show little information within the consonants themselves. When bands of energy appear in the final portion of the consonant or after a release, the band near the level of the vowel F2 is lower in the case of the emphatic. In word-final position, /ð/ and /ð̣/ both show a release, which is followed by more energy in the case of /ð̣/ than that of /ð/.

The upper/lower pharyngeal pairs, /x/, /ħ/ and /R/, /ʕ/, do not correspond to the non-emphatic/emphatic pairs in their effects on adjacent vowels; the upper pharyngeals affect the vowels like emphatics. The bands of energy in the upper pharyngeals behave as one would expect of emphatics. This suggests that /x/ might better be classified as a uvular fricative.

/aa/ is a back vowel before and after /x/ and /R/; /ħ/ and /ʕ/ do not determine a back vowel as they would if they corresponded to the emphatics. In the environment of /ii/, the band of energy in the friction of /x/ which joins F2 of /ii/ shows a steep slope which resembles the slope of the F2 transitions of /ii/ in the environment of an emphatic consonant. The corresponding band in the friction of /h/ slopes less steeply, being only slightly below the level of F2 of /ii/. There is F2 transition when /ii/ is in the environment of both /R/ and /ʕ/. The band of energy which joins F2 of /ii/ is lower in the case of /R/, effecting a lower F2 adjacent to the consonant, and thereby a steeper F2 transition. The upper pharyngeals /x/ and /R/ also effect a lower F2 of /uu/ adjacent to the consonant. The lower pharyngeals contain a band of energy within the friction which is higher than F2 of /uu/ and slopes to join the vowel F2.

The bands of energy within the upper and lower pharyngeals are somehat different from those that Delattre predicted. The lowest band of energy in /ħ/ and /ʕ/ is at the level of, rather than above, F1 of /aa/. When low bands occur in /x/ and /R/, they too are lower than predicted. Delattre's predictions fail to account for the behavior of the bands of energy which join F2 of /ii/ and /uu/. It seems that /ii/ can be articulated simultaneously with /ħ/ and /ʕ/, the root of the tongue and the tip being able to move more or less independently. Movement of the body of the tongue is necessary in the transition to /ii/ from /x/ and /R/, which are articulated with the back of the tongue. This movement is seen in the slope of the band of energy within the consonant and of the vowel F2. On the other hand, the back of the tongue is more nearly in the position for articulation of /uu/ in the articulation of the upper than that of the lower pharyngeals.

Thus it seems that the upper/lower pharyngeal pairs should not be analogized to the non-emphatic/emphatic pairs on the basis of the less-back/back similarity, as has been suggested (Delattre 1970). This study suggests that the lower pharyngeal/upper pharyngeal pairs might be considered non-emphatic/emphatic pairs. The upper pharyngeals are articulated with the back of the tongue, as are those consonants agreed to be emphatics, and have similar effects on adjacent vowels. The lower pharyngeals, articulated with the root rather than the back of the tongue, affect adjacent vowels as non-emphatics.

The trill occurring in the production of /R/ is produced with incomplete closure at the uvula, as indicated by the intermittent reductions in the intensity of the consonant rather than interruptions of it; this agrees with Delattre's observation. Friction was not evident in the spectrograms of /ʕ/, as Stevens found. The vowel-like appearance of /ʕ/ suggests that it is an approximant, rather than a fricative.

Table I

Formant Frequencies of /aa/

	after:				before:			
	onset	s.s.	onset	s.s.	term.	s.s.	term.	s.s.
	t		ṭ		t		ṭ	
F1	550	650	500	500	700	750	700	850
F2	1800	1500	1000	1000	1500	1500	1100	1250
F3	2300	2300	2300	2450	2400	2400	2200	2300
F2-F1	1250	850	500	500	800	750	400	400
	d		ḍ		d		ḍ	
F1	500	500	500	600	500	750	600	650
F2	1800	1700	1000	1050	1750	1500	1000	1000
F3	2500	2400	2500	2500	2300	2300	2350	2200
F2-F1	1300	1200	500	450	1250	750	400	350
	s		ṣ		s		ṣ	
F1	600	700	600	600	500	500	500	500
F2	1500	1300	1200	1200	1450	1200	1000	1150
F3	2400	2400	2500	2300	2400	2400	2300	2300
F2-F1	900	600	600	600	950	700	500	650
	ð		ð̣		ð		ð̣	
F1	700	700	700	700	800	800	750	750
F2	1500	1450	1200	1250	1400	1450	1250	1300
F3	2400	2300	2400	2300	2500	2500	2500	2350
F2-F1	800	750	500	550	600	650	500	550
	k		q		k		q	
F1	450	700	450	450	650	700	750	750
F2	1850	1750	1250	1250	1500	1500	1200	1300
F3	2300	2350	2250	2300	2250	2300	2250	2300
F2-F1	1400	1050	800	800	850	800	450	550

Table I (cont.)

	x		ħ		x		ħ	
F1	750	750	800	800	750	750	900	900
F2	1300	1300	1500	1500	1200	1200	1200	1200
F3	2500	2500	2400	2400	2300	2300	2250	2250
F2-F1	550	550	700	700	450	450	300	300
	R		ʕ		R		ʕ	
F1	600	650	800	750	600	800	800	800
F2	1200	1200	1450	1450	1200	1250	1200	1200
F3	2300	2300	2250	2250	2300	2300	2300	2300
F2-F1	600	550	650	600	600	450	400	400

Table II

Formant Frequencies of /ii/

	after:				before:			
	onset	s.s.	onset	s.s.	term.	s.s.	term.	s.s.
	t		ṭ		t		ṭ	
F1	500	500	500	500	450	450	400	400
F2	2200	2200	1250	2250	2200	2200	1300	2200
F3	2750	2800	2600	2800	2700	2700	2300	2500
F2-F1	1700	1700	750	1750	1750	1750	900	1800
	d		ḍ		d		ḍ	
F1	450	450	350	350	400	400	350	350
F2	2000	2050	1300	2250	2100	2250	1300	2200
F3	2250	2300	2500	2450	2700	2750	2500	2700
F2-F1	1550	1600	950	1900	1700	1850	950	1850
	s		ṣ		s		ṣ	
F1	350	350	300	300	350	350	350	350
F2	2000	2050	1700	1950	2100	2150	1550	2000
F3	2600	2650	2400	2400	2500	2500	2500	2500
F2-F1	1650	1700	1400	1650	1750	1800	1200	1650
	ɣ		ɣ̣		ɣ		ɣ̣	
F1	300	300	350	350	300	300	400	400
F2	2200	2200	1600	2200	2000	2200	1100	2200
F3	2500	2700	2350	2800	2400	2800	2500	2500
F2-F1	1900	1900	1250	1850	1700	1900	700	1800
	k		q		k		q	
F1	450	450	500	500	400	400	400	400
F2	2100	2100	1850	2300	2200	2300	1500	2300
F3	2700	2700	2550	2750	2750	2800	2750	2800
F2-F1	1550	1550	1350	1800	1800	1900	1800	1900

Table II (cont.)

		x		ħ		x		ħ
F1	350	350	400	400	300	300	350	350
F2	2200	2250	2250	2250	2000	2200	2200	2200
F3	2600	2750	2800	2700	2600	2650	2700	2650
F2-F1	1850	1900	1850	1900	1700	1900	1850	1850
		R		ʕ		R		ʕ
F1	350	350	350	350	500	500	500	500
F2	1450	2200	2100	2250	1550	1950	1850	2150
F3	2350	2750	2650	2700	2500	2450	2350	2400
F2-F1	1100	1850	1750	1900	1050	1450	1350	1650

Table III

Formant Frequencies of /uu/

	after:				before:			
	onset	s.s.	onset	s.s.	onset	s.s.	onset	s.s.
		t		ṭ		t		ṭ
F1	300	300	400	400	350	350	400	400
F2	900	750	800	750	1450	750	1150	750
F3	--	--	--	--	2300	2500	2300	2300
F2-F1	600	450	400	350	1100	400	700	350
		d		ḍ		d		ḍ
F1	400	400	350	350	350	350	450	450
F2	850	750	700	700	700	700	700	700
F3	2300	2300	2300	--	2300	--	--	--
F2-F1	450	350	350	350	350	350	250	250
		s		ṣ		s		ṣ
F1	350	350	400	400	400	400	350	400
F2	1250	750	1000	800	1300	800	1000	800
F3	2300	2300	2300	2300	2500	2450	2400	2450
F2-F1	900	400	600	400	900	400	640	400
		ɣ		ɣ̣		ɣ		ɣ̣
F1	350	400	400	400	300	300	400	350
F2	850	850	800	800	800	800	800	750
F3	--	--	2200	2200	--	--	2300	2300
F2-F1	500	500	400	400	500	500	400	400
		k		q		k		q
F1	450	400	500	450	500	500	500	500
F2	800	800	800	900	850	900	850	900
F3	2300	2300	2400	2400	--	--	--	--
F2-F1	350	400	300	450	350	400	350	400

Table III (cont.)

	x		ħ		x		ħ	
F1	250	250	300	300	250	250	300	300
F2	800	800	800	750	750	750	800	750
F3	--	2250	2300	--	--	--	2300	--
F2-F1	550	550	500	450	500	500	500	450

	R		ʕ		R		ʕ	
F1	350	350	400	400	450	450	500	500
F2	750	750	850	800	750	800	850	800
F3	2400	2300	2100	2200	--	2200	--	--
F2-F1	400	400	450	400	300	350	350	300

Table IV

Onset and Terminal F2 Transition Frequencies

	/aa/	/aa_/	/_ii/	/ii_/	/_uu/	/uu_/	Range
t	1800	1500	2200	2200	900	1450	900-2200
ṭ	1000	1100	1250	1300	800	1150	800-1250
d	1800	1750	2000	2100	850	700	700-2100
ḍ	1000	1000	1300	1300	700	700	700-1300
s	1500	1450	2000	2100	1250	1300	1250-2100
ṣ	1200	1000	1700	1550	1000	1000	1000-1700
ð	1500	1400	2200	2000	800	800	800-2200
ð̣	1200	1250	1600	1100	800	800	800-1600
k	1850	1500	2100	2200	800	850	800-2200
q	1250	1200	1850	1500	800	850	800-1850
x	1300	750	2200	2000	800	750	750-2200
ħ	1500	900	2250	2200	800	800	800-2250
r	1200	600	1450	1550	750	750	600-1550
ʕ	1450	800	2100	1850	850	850	800-1850

Table V

Duration of Closure and Burst (+Aspiration) of Stops

Duration of closure of stops (msecs)

	/_aa/	/aa_/	/_ii/	/ii_/	/_uu/	/uu_/
t	--	104	--	86	--	100
ṭ	--	114	--	100	--	114
d	134	100	156	80	70	100
ḍ	60	104	120	100	90	96
k	--	82	--	84	94	96
q	--	96	--	114	94	108

Duration of burst (+aspiration) of stops (msecs)

	/_aa/	/aa_/	/_ii/	/ii_/	/_uu/	/uu_/
t	44	84	80	64	60	46
ṭ	10	24	20	2	5	2
d	16	10	26	24	24	24
ḍ	5	2	2	2	10	10
k	54	96	64	102	104	84
q	10	70	10	30	36	32

Table VI

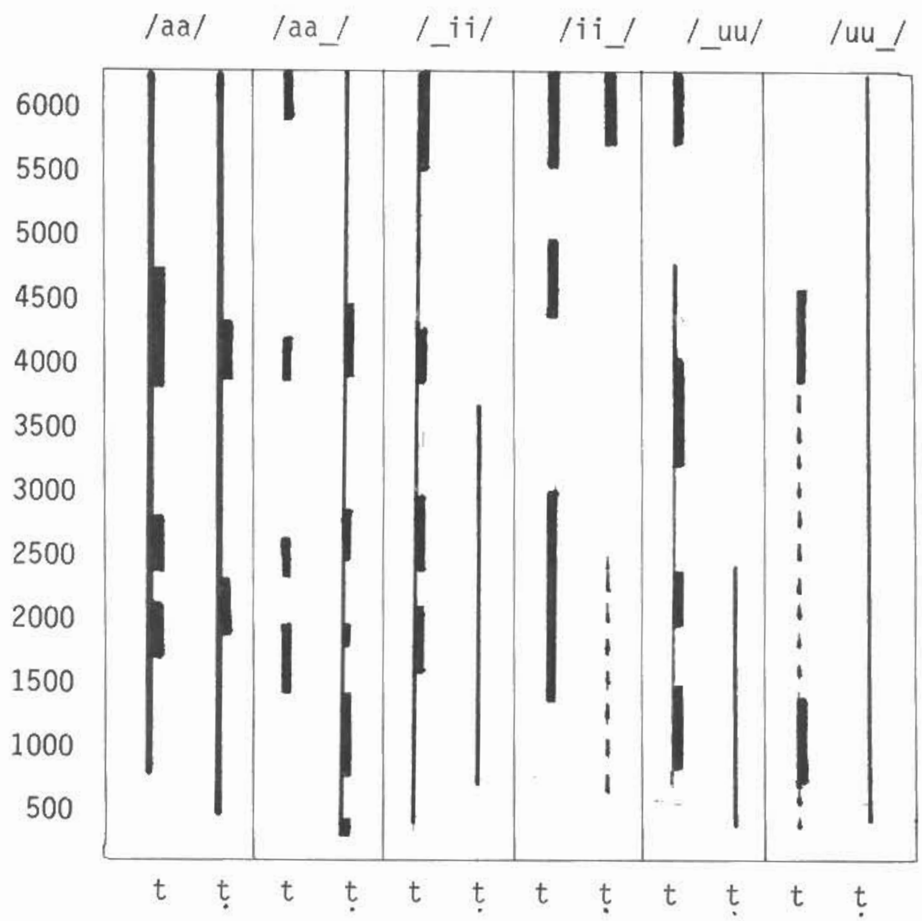
Duration of Continuant Consonants (msecs)

	/_aa/	/aa_/	/_ii/	/ii_/	/_uu/	/uu_/
s	140	210	140	160	170	210
ṣ	164	204	144	150	150	200
ð	184	196	180	96	100	116
ð̣	180	192	180	116	80	120
x	160	304	200	178	160	184
ħ	224	210	186	180	230	220
R	180	130	180	116	100	124
ʕ	240	176	104	96	132	104

Table VII

Energy Visible in Burst and Aspiration

of /t/ and burst of /ṭ/



Dotted line indicates very slight energy.

Table VIII

Energy Visible in Burst of /d/ and /d/ (cps)

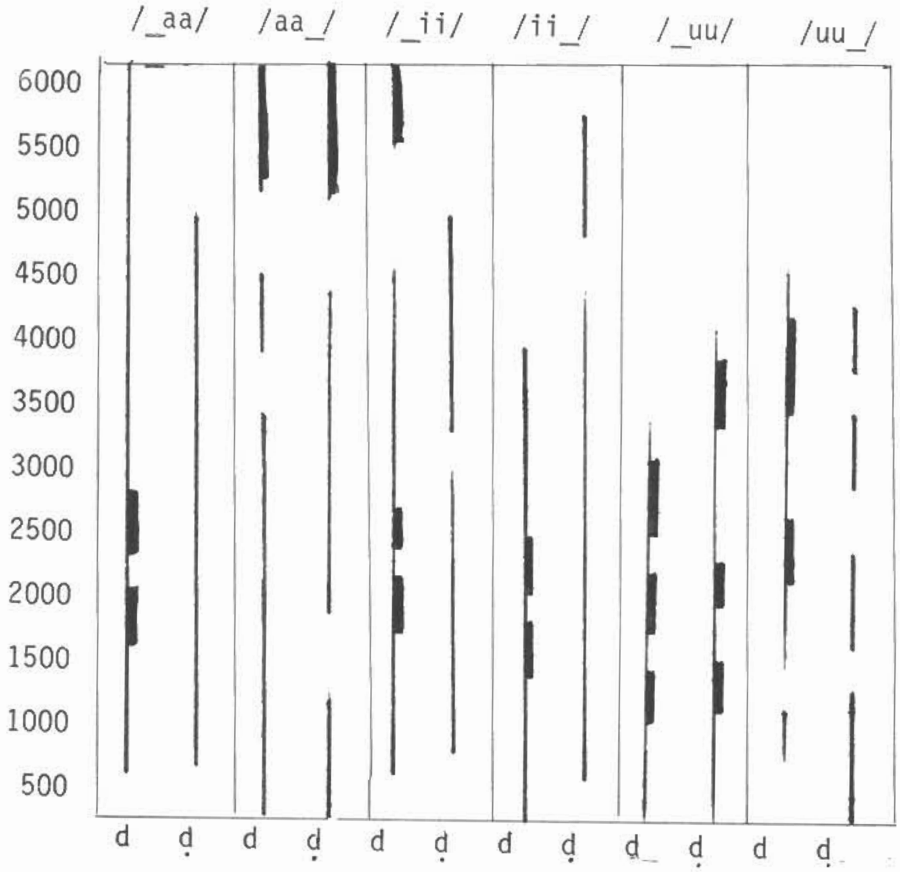
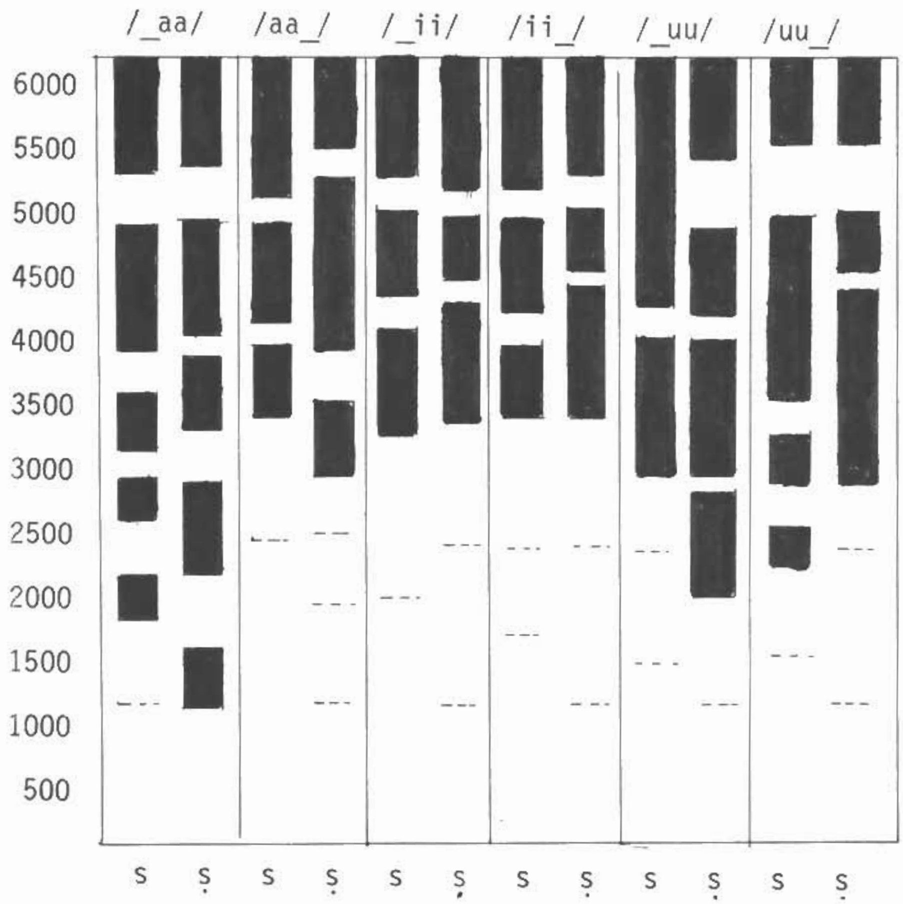


Table IX

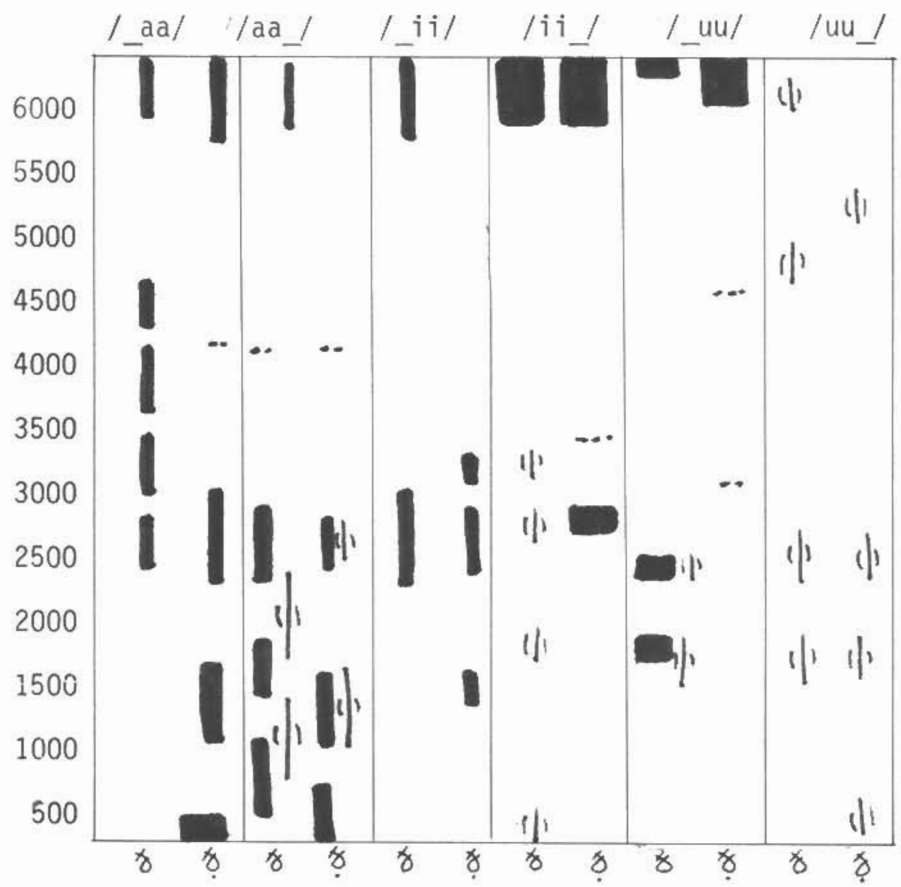
Energy Visible in /s/ and /ṣ/ (cps)



Dotted line indicates faint area of energy.

Table X

Energy Visible in /ɣ/ and /ɣ̣/ (cps)



Shortened bars indicate energy only in portion of consonant adjacent to the vowel.
Bars in parentheses indicate energy which follows a release.

Table XI

Energy Visible in Burst and Aspiration of /k/ and /q/

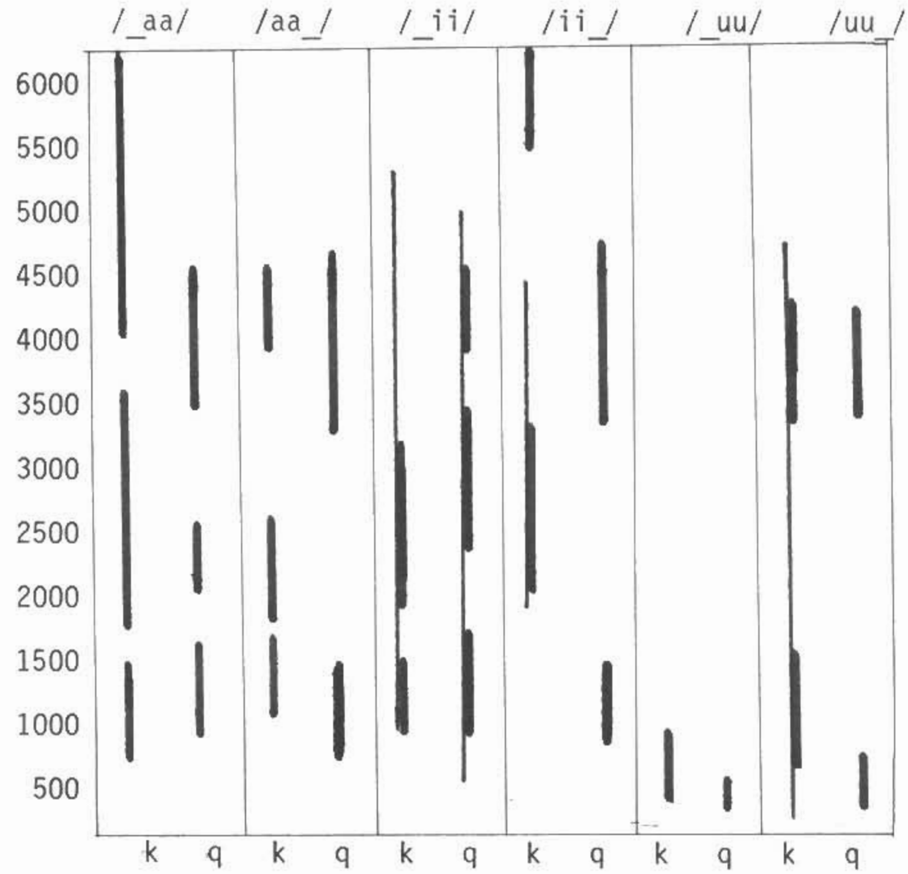
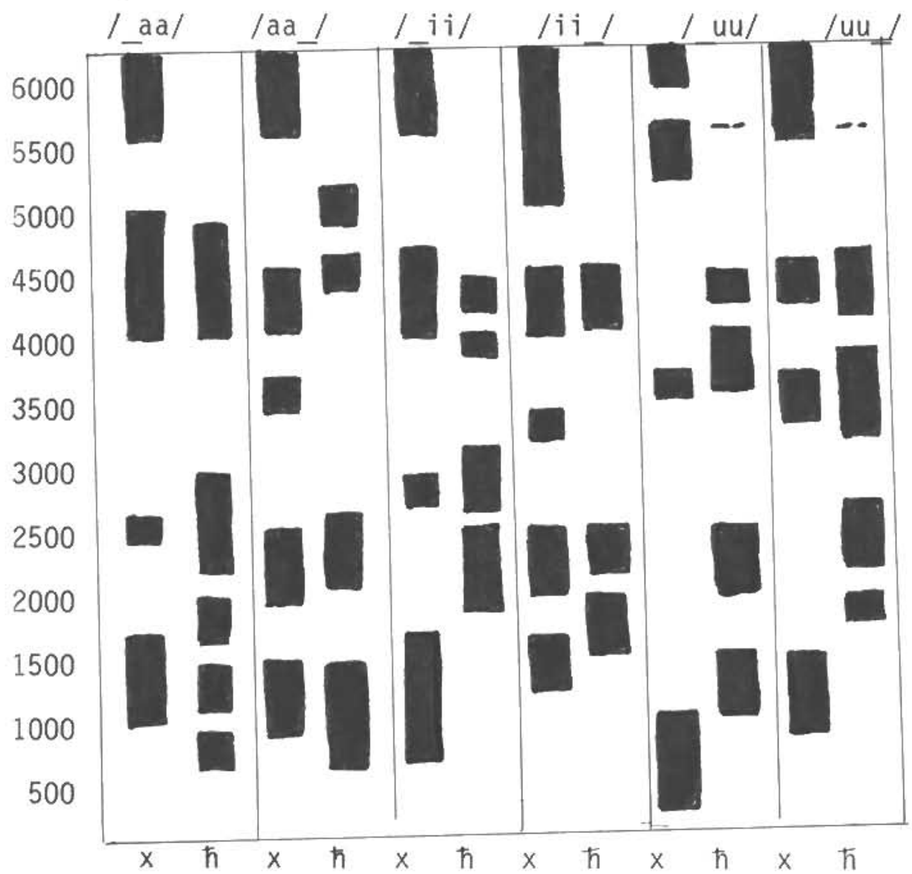


Table XII

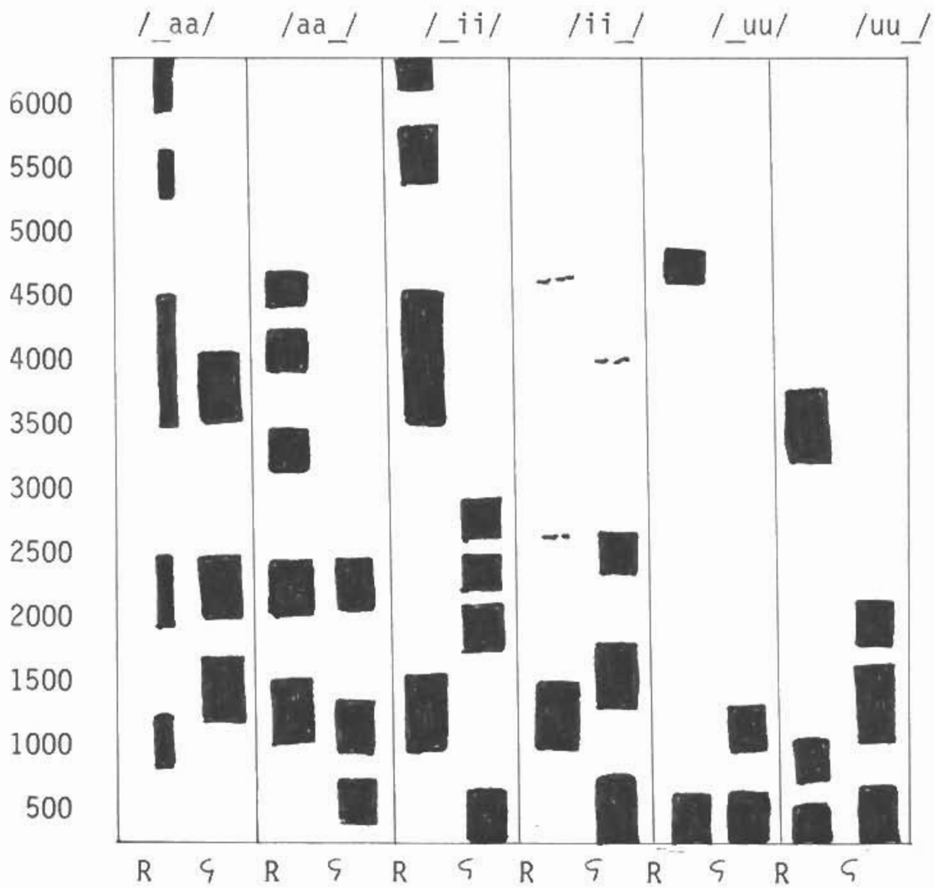
Energy Visible in /x/ and /ħ/ (cps)



Dotted line indicates faint area of energy.

Table XIII

Energy Visible in /R/ and /ʕ/ (cps)



Shortened bars indicate energy only in portion of consonant adjacent to the vowel.
Dotted line indicates faint area of energy.

Appendix

/taab/	repented	/saar/	walked
/ṭaab/	recovered	/ṣaar/	became
/haat/	stripped	/qaas/	measured
/haaṭ/	surrounded	/qaaṣ/	traced
/tiin/	figs	/yasiir/	walks
/ṭiin/	clay	/yaṣiir/	becomes
/siit/	reputation	/qiis/	measure!
/siiṭ/	whipped	/qiiṣ/	trace!
/tuub/	repent!	/suur/	fence
/ṭuub/	blocks	/ṣuur/	formed
/quut/	food	/buus/	kiss!
/quuṭ/	proper noun	/buuṣ/	flute
/daaʕ/	claim!	/ðaal/	letter name
/ḍaaʕ/	lost	/ð̣aal/	lost
/Istaʕaad/	resumed	/ʕaað/	sheltered
/Istaʕaaḍ/	compensated	/ʕaað̣/	preached
/diir/	convent	/ðiid/	protected
/ḍiir/	harmed	/ð̣iid/	nonsense word
/ħiid/	avoid!	/biið/	loosened
/ħiiḍ/	menstruate!	/biið̣/	lay and egg!
/bəduur/	christened	/naðuur/	vows
/bəḍuur/	clitoris	/nað̣uur/	good-looking
/quud/	lead!	/waʕuuð/	ceremonies
/quuḍ/	demolished	/waʕuuð̣/	medallion
/kaal/	measured	/ʃiix/	aged
/qaal/	said	/ʃiiħ/	herbs
/ðaak/	that	/xuur/	moo!
/ðaaq/	tasted	/ħuur/	nymphs
/kiil/	measure!	/kuux/	hut
/qiil/	it is said	/kuuħ/	throw!
/ðiik/	that	/Raab/	was absent
/ðiiq/	was tasted	/ʕaab/	deplored
/wakuur/	birds' nests	/raaR/	deviated
/waquur/	dignified	/raaʕ/	shepherd
/fuuk/	your mouth	/Riib/	be absent!
/xaal/	maternal uncle	/mariiR/	muddy
/ħaal/	condition	/mariiʕ/	horrifying
/raax/	slacken	/wuRuud/	children
/raaħ/	left	/wuʕuud/	vows
/xiik/	your brother	/furuuR/	vacancies
/ħiik/	plotted	/furuuʕ/	branches

NOTES

1 /x/ may be a voiceless uvular fricative; in Delattre's tracings, /x/ resembles /q/ more than /k/.

2 This study indicates that /ʕ/ is an approximant rather than a a fricative.

3 /r/ was not included in this study of consonant pairs due to the lack of a front counterpart.

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