AN ACOUSTIC TIMING STUDY OF PHARYNGEAL AND LARYNGEAL FRICATIVES IN ARABIC

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ABSTRACT

In this paper a study, on the *acoustic level*, of the temporal control for back fricatives of Arabic is presented. These consonants are examined in different vocalic quality and quantity contexts. Our results show a tendency for a global control of the VCV domain. We thus focus on the *timing* of our fricatives within this temporal span.

1. INTRODUCTION

Knowledge of articulatory coordinations underlying the production of fricatives requires a precise description of the timing of their component *gestures*. This paper deals with the temporal organization of three fricatives in Arabic :

- the pharyngeal fricatives [ʕ] and [ɦ], respectively voiced and unvoiced, produced by a constriction of the low-pharynx ;
- the unvoiced glottal fricative [h], produced by a constriction at the laryngeal level.

The notion of *relative duration* proposed by Lehiste [6] is exploited in this investigation ; so also is the concept of *cycles* or *temporal domains* and *phases* borrowed from the field of motor control and transferred to the study of speech production by Tuller and Kelso [8], among others. On this score, events related to specific articulatory gestures - like onset/offset of vocal fold vibrations or vocal tract closing or opening gestures - are detected on the acoustic signal. Determined temporal coordinations of these events give us our phases and cycles (cf. *infra*).

2. CORPUS

Our corpus is a set of 18 short sentences, each containing a [C1V1C2V2C3 V3] item, with C1=[s], V1=[a], C2=[ʕ ɦ h], V2=[a, i, u, a:, i:, u:], C3=[l] and V3 =[a]. The carrier interrogative sentence is of the type [manC1V1C2V2 C3V3], for example: [mansaʕala] meaning "Who coughed ?"

3. RECORDINGS

Recordings were carried out in a sound proof room. The speaker, a male Algerian adult, had to repeat each sentence 13 times in front of a directive microphone 'ELECTRET' placed at a distance of 20 cm from his mouth. The signal, digitized by a SONY P.C.M. and sampled at 40 kHz, was finally stored on a BETAMAX videotape. The subject had been instructed to say the sentences in a normal conversational rate, at a regular rhythm, with a slight pause before each sentence. The sentences were presented to the speaker in a random order.

4. MEASUREMENTS

Two vocalic phases, DV1 and DV2, and a consonantal one T were retained. These phases were determined with the help of articulatory-acoustic events proposed by Abry et al. [1]:

- the vocalic phases DV1 and DV2 are specified as the duration between the onset (VVO) and the offset (VVT) of the clear formant structure of the vowels (V1 and V2) that flank the fricative ;
- the consonantal phase T is defined as the duration between the offset of the clear formant structure of vowel V1 and the onset of the clear formant structure of vowel V2.

Phase measurements for vowels V1 and V2 (respectively phase DV1 and DV2) and for the consonantal phase T, are given first in absolute values, and then in relative values with respect to the VCV temporal base.

5. DATA ANALYSES

5.1 Vocalic quantity DV2 (ms)

It is well known that the temporal control of vowel duration in Arabic can be linguistically significant (see for example [3], [4] and [5]). Our results, presented in table 1, confirm this vocalic quantity contrast: a global observation of our data shows that short vowels have a mean duration of 95 ms, and that long vowels have a mean duration of 255 ms with, in both cases, small standard deviations. Vowel duration ratio is thus around 2.5, which is indeed significant. Results also show that vowel lengthening is noticeably influenced by the consonantal context. Finally, it can be observed for the three consonantal contexts, that the most significant vocalic quantity contrast is obtained with vowel [a].

Table.1. Vocalic phases

			[a]	[i]	[u]
[ɦ]	B	m	89	84	87
		σ	6	8	10
	L	m	247	212	241
		σ	20	25	20
[ʕ]	B	m	95	88	95
		σ	20	12	10
	L	m	310	231	264
		σ	30	20	22
[h]	B	m	97	106	109
		σ	13	15	10
	L	m	297	220	-
		σ	30	30	-

5.2 Consonantal phase T

Table 2 shows that average consonantal durations, calculated for the entire data, vary with vocalic quantity contrast: globally, the consonantal duration T has a mean value of 105 ms in short vocalic contexts, whereas the average value for T in long vocalic contexts is 125 ms. This finding seems to support the notion of a preprogrammed attribution of consonantal values with regards to the vocalic linguistic task, short versus long (See [7] for a related discussion on this latter notion). Furthermore, separated analyses of our data for each fricative show comparable influences of the vocalic contexts on the three fricatives.

Table. 2. Consonantal phases (ms)

			[a]	[i]	[u]
[ɦ]	B	m	136	129	119
		σ	10	6	10
	L	m	154	147	133
		σ	15	18	13
[ʕ]	B	m	85	88	66
		σ	15	12	10
	L	m	81	103	87
		σ	10	8	10
[h]	B	m	108	101	91
		σ	13	20	10
	L	m	141	115	-
		σ	20	15	-

5.3 The significant temporal domain

As mentionned above, vocalic quantity contrast is portrayed not only by a difference in intrinsic vowel duration (Table 1), but also by a variation of consonantal durations. Moreover, such durational differences depend on consonant type. We posit therefore that the vocalic quantity contrast is not simply limited to the vocalic phase. To be able to propose hypotheses on the type of sequence which is temporally programmed in this contrast, we looked for the domain that maximizes these differences [2]. We therefore applied the Student test to our data so as to evaluate

Table.3. Student test for absolute durations

	PAR	t		PAR	t
	VCV	22,6		VCV	19,3
aɦa	DV2	20,9	aʕa	DV2	17,8
/	CV	15,8	/	CV	13,3
	T	2,51		T	-
aɦaa	VC	-	aʕaa	VC	-
	DV1	-		DV1	-
	VCV	13,2		VCV	18,6
aɦi	DV2	13,7	aʕi	DV2	17,4
/	CV	9,3	/	CV	13,1
	T	2,99		T	-
aɦii	VC	6,57	aʕii	VC	-
	DV1	-		DV1	-
	VCV	20,1		VCV	29,2
aɦu	DV2	18,7	aʕu	DV2	20,3
/	CV	20,2	/	CV	13,8
	T	2,78		T	2,98
aɦuu	VC	-	aʕuu	VC	-
	DV1	-		DV1	-
	VCV	16,6		VCV	11,8
aha	DV2	15,6	ahu	DV2	9,03
/	CV	10,3	/	CV	8,1
	T	3,61		T	2,98
ahaa	VC	-	ahuu	VC	-
	DV1	-		DV1	-

the distinctive power of the phases described above and also that of combinations of these phases: VC=DV1+T, CV=T+DV2, and VCV=DV1+T+DV2. Only significant values of t (a<0.05) are presented in table 3. In general, the VCV domain provides the most significant temporal base for class distinctions; one might therefore think, in the absence of more data on speech rate variation, that the VCV span is the programmed entity for these specific linguistic tasks: actually, vowel phonological differences seem to spread out significantly to the entire VCV sequence.

5.4. Influence of the vocalic context.

Let us now take a look at the influence of vocalic contexts [i], [a], [u], on the fricatives within the VCV domain.

In the case of short vowels, the total duration of the cycle is not affected by vocalic variations; however, consonantal durations show significant differences:

-for both [ʕ] and [ɦ], we observe significant differences in [a] vs. [u] contexts, and in [u] vs. [i] contexts, but not in the [a] vs. [i] ones.

-for [h] we observe only significant differences in [a] vs. [u] surroundings.

Therefore, in the case of short vowels, place of articulation does not seem to have much influence on consonantal duration, but vowel rounding seems to induce modifications in this duration.

As concerns long vowels, it can be noticed that vocalic length (V2) varies, depending on both place of articulation and lip shape characteristics. From a general point of view, all component phases of the VCV cycle are modified as a function of vowel type. However, the total duration of the complete cycle remains more or less stable.

What can be observed therefore, is a temporal restructuring of phases within the VCV cycle for each vowel class; however, the control of the total duration of this cycle evokes an isochronous constraint principle. These results corroborate the hypothesis addressed above regarding the temporal programming of the VCV sequence as whole (cf. *supra*).

Average values for VCV domains are different for the three fricatives and for short versus long vowels:

- [ɦ]=210 ms for short vowel vs. 360 ms for long vowels;
- [ʕ]=180 ms for short vowel vs. 330 ms for long vowels ;
- [h]=200 ms for short vowel vs. 400 ms for long vowels.

But one must be cautious in generalizing such results concerning this temporal restructurings, as long as speech rate has not been explicitly introduced in to our experimental paradigm.

6. TIMING OF THE FRICATIVES IN THE VCV DOMAIN

How do constituent phases of the VCV domain help to distinguish the different fricative classes in relation to this domain ? We observed these relative differences for the voiced/unvoiced contrast [ʕ] vs. [ɦ] and for differences in place of articulation [ɦ] vs. [h] in the various vocalic contexts. Figures 2a and 2b give the structural types of the VCV sequences for each context.

Phase DV1 discriminates the voiced vs. unvoiced classes [ʕ] vs. [ɦ], but does not distinguish the difference in place of articulation for the unvoiced [ɦ]/[h].

Phase T discriminates the voiced vs. unvoiced classes ([ʕ]/[ɦ]), but the distinction associated with place of articulation observed in short vowel contexts disappears completely with vowel lengthening.

Phase DV2 is weaker than phases DV1 and T in discriminating consonantal classes, for voiced/unvoiced contrasts. When DV2 does exist as a distinctive parameter in opposing place of articulation, its t values are comparable with those obtained for phase T, and better than those obtained for phase DV1.

7. CONCLUSION

In the study of the acoustic timing of fricatives in Arabic, the analysis of absolute durations shows a global control of the VCV temporal base. Within this cycle, the voiced vs. unvoiced distinctions are made essentially by a temporal reorganization of the VC domain, which corresponds to the combination of phases DV1 and T.

The distinction of place of articulation is obtained generally by a restructuring of of T and DV2 corresponding to the CV span.

These preliminary results must be consolidated by a study that includes speech rate as the controlled perturbing factor of vocalic quantity and consonantal types.

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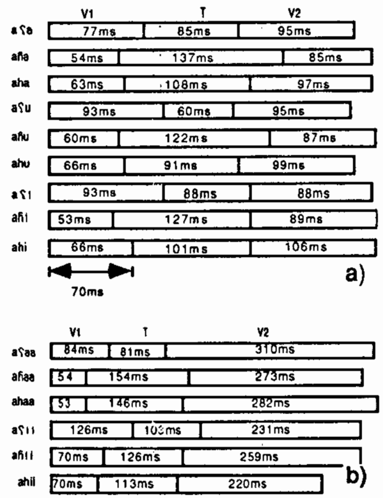

Fig.1.Absolute durations
a) short vowels
b) long vowels

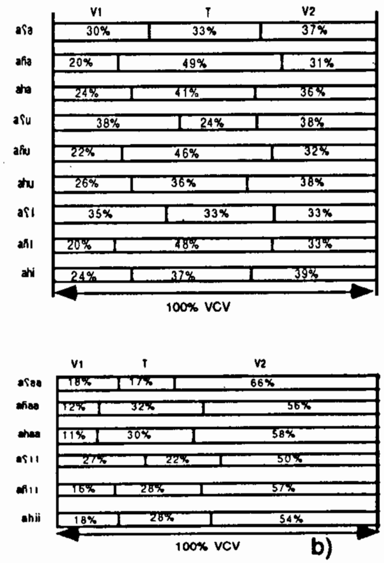

Fig.2 Relative durations in VCV domain
a) short vowels
b) long vowels