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PLOSIVE AND FRICATIVE GEMINATES IN TARIFIT
AN ARTICULATORY AND ACOUSTIC STUDY

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ABSTRACT

This investigation, based on acoustic data for six native speakers, and on X-ray data for two native speakers, reports on gemination in Tarifit Berber (spoken in Northern Morocco). It presents results of articulatory and acoustic investigations of singleton and geminate voiced and voiceless consonants, produced in word initial, word medial, and word final positions, at a normal and at a fast speaking rate. Speech rate is varied in order to evaluate the robustness of the phonological contrast. Special attention is paid to the timing of tongue gestures in producing this phonological contrast.

1. THE PROBLEM

Several studies have sought to determine acoustic cues for gemination in many languages: see *e.g.* [1] to [19]. One consistent acoustic characteristic shared by geminates is that they are significantly longer than their singleton counterparts (see [18] for a review of 24 languages opposing singletons to geminates). Lahiri & Hankamer [9], for example, investigated the timing properties of singleton/geminate voiceless stops in Turkish and Bengali and showed that closure duration is the most important correlate of the geminate/singleton opposition for both languages. In addition, VOT is longer for geminates in Turkish while vowel duration is unaffected. In Bengali, vowel duration is shorter before geminates, but VOT is unaffected. In his acoustic study on gemination in four unrelated languages – Levantine Arabic, Standard Hungarian, Indonesian Madurese, and Swiss-German Bernese – Ham [5] found that the only acoustic correlate that significantly distinguishes geminates from singletons is closure duration. Positive VOT or burst duration does not contribute to the contrast between these consonants in any of these languages. Other findings suggest, however, that rather than being restricted to durational differences alone, the implementation of gemination may have implications for most if not all of a form’s phonetic shape involving vowel and consonant qualities and resonances. In Malayalam, for example, forms containing geminates differ systematically from those without geminates in terms of phonation, tense vs. lax articulations, consonant and vocalic resonances as well as patterns of articulatory variability in adjacent consonants [11].

The acoustic and articulatory characteristics of geminates have been extensively examined in Tashlhiyt, a related Berber language (see e.g. [12], [15], [17], and [18]). These studies have reported that geminates are significantly longer than their singleton counterparts. Based on the temporal information about the articulatory closure using EPG, Ridouane [17] showed that these durational differences were robustly maintained for voiceless stops even in utterance-initial position, though these durational differences are not perceptible. In addition to closure duration differences, gemination was also found to significantly shorten the preceding vowel.

The majority of the production studies on geminates has been limited to intervocalic geminates, a fact which is unsurprising given that these segments are most widely found in this environment. The acoustic characteristics of initial and final geminates have not been subject to as much investigation. Tarifit Berber contrasts singletons and geminates in intervocalic as well as in initial and final positions.

In this study we present results of an investigation of the acoustic and articulatory correlates that distinguish singleton stops and fricatives from their geminate counterparts. The novelty in the present study, compared with previous work [22] and [23], is that investigations consider all obstruents in three positions: word-initial, word-medial, and word-final positions. The aim is to determine whether position in the word shapes variability in singleton/geminate contrast. In addition, we varried speech rate in order to determine whether geminate contrast is resistant to increased speaking rate.

It is *hypothesised* on the *acoustic level* that, as reported in the literature, geminates would have longer closure durations than singletons (*hypothesis 1*). The duration of flanking vowels may be affected by that of geminate consonants (*hypothesis 2*): they would be shorter in this environment [10], in case of syllable isochrony. VOT could be longer for geminates, as their occlusion phase is usually remarkably long, thus retarding onset of voicing, due to high intra-oral pressure (*hypothesis 3*).

On the *articulatory level*, contact-extent for plosives and length of maximum constriction for fricatives, partly underlying consonantal closure, respectively for these two categories, would be correlatively longer for geminates (*hypothesis 4*). If geminates do shorten adjacent vowels, vowel constriction opening may vary as a function of this coarticulatory influence; the size of the constriction would be reduced as vowel duration reduces (*hypothesis 5*) [21].

2. METHOD

The entire *corpus* (plosives and fricatives) consisted of 54 sentences of 4 to 6 syllables, comprising 27 minimal pairs that were inserted in these meaningful carrier sentences. The speech material analysed here consists of all the 27 minimal pairs, contrasting singleton stops and fricatives with their geminate counterparts, in three positions: word initial, word medial, and word final. The plosives examined were: /t, d, k, g, q/ *vs.* /tt, dd, kk, gg, qq/. The fricatives were: /s, z, ʃ, ʒ/ *vs.* /ss, zz, ʃʃ, ʒʒ/. All target sequences were inserted in the same carrier sentence: /ini_____iʒ umar /, meaning "Say_____once". For the acoustic investigation, the six subjects (two women and four men, from 24 to 30 years old) were seated comfortably at a distance of 20 cm from the microphone, in an anechoic room. All tokens were repeated twelve times by the six speakers, in the two rate conditions. All pairs of sentences had the same number of syllables.

In the X-ray experiment (25 frames/sec), these minimal pairs were produced once at a normal (self-selected) speaking rate, by two speakers (two men).

The *X-articulator* software, developed at LORIA in Nancy within the DOCVACIM project [20], includes various tools devoted to processing cine-radiographic data. These tools comprise semi-automatic algorithms to monitor speech articulators, a graphic interface which allows editing these contours, and also tools devoted to data analyses and elaboration of articulatory models. These X-ray data processing tools have allowed creating entire contours corresponding to the position and movements of the speech articulators. Hence, for this specific investigation, *measurement parameters* for *vocal tract configurations* were determined related to constriction opening within the vocal tract. They provide for plosives: tongue tip to alveolar ridge, tongue body-to-soft palate, and tongue body-to-uvula contact-extents (mm). For fricatives and vowels adjacent to or flanking target consonants, constriction opening (mm) was monitored throughout the entire vocal tract, from the alveolar region to the larynx.

Temporal events were detected on the *audio* signal, and specific intersegmental and intrasegmental timing relations between these events allowed determining acoustic durations (ms) which correspond respectively to articulatory opening and closing gestures, and also to timing between supraglottal and glottal gestures. Thus, for intersegmental timing relations, vowel durations were specified as intervals between onset and offset of a clear formant structure, for V1 and V2. Corollary, closure duration was measured, between vowels, from offset to onset of clear vocalic formant structures. As concerns intrasegmental timing relations, VTT (Voice Termination Time, measured from vowel offset to the last voicing pulse within the voiceless plosive), plosive occlusion (i.e. closure duration excluding VOT for voice plosives), the acoustic silent phase (for voiceless plosives) and VOT (the interval between the burst-release of the plosive and onset of a clear formant structure of the subsequent vowel) were also acquired.

General remark on *acoustic measures*: It was expected following results usually reported in the literature on quantity contrasts that, in spite of any eventual compression that measured parameters might undergo, due to increased speaking rate, differences in consonantal closure (the privileged parameter of the phonological contrast) would nonetheless be maintained. Taking into account the elasticity of speech signals [4], which vary as a function of speakers, speaking rates, diverse contexts…, differences in *absolute values* between geminates and singletons were normalised. Thus, the proportion of consonantal closure within the CV2 syllable was calculated. It has indeed been shown [10] that it is within this CV domain that temporal contrasts for consonantal quantity are maximised. *In fine*, therefore, fine grained analyses of the data, together with our conclusions, will be drawn from these *relative values*.

3. RESULTS

All statistical analyses of the acoustic data were made using Prism® software. Two-way analyses of variance (ANOVA) were thus carried out for all variables (V1, VTT, consonantal closure, occlusion / acoustic silent phase, VOT, V2) in order to determine the statistical significance of main effects (*gemination*, *voicing*, *place of articulation* and *speech rate*) followed by a *Bonferroni post-hoc* pair-wise test, so as to compare the reproducibility of mean values within speakers. Only results significant with a probability of less than five per cent ($p<0.05$) were retained. Since the measured parameters differed between plosives and fricatives, separate statistical analyses were carried out for the two categories. Two *main effects* proved to be statistically significant for both the intersegmental *consonantal closure* and intrasegmental occlusion/silent phase variables: *gemination* ($p<0.0001$) and *speech rate* (0.0001). Hence, *post-hoc* pair wise comparisons (*Bonferroni*) were carried out on mean values of absolute and relative values only for these variables.

The *acoustic data* reveal that consonantal closure and the occlusion/silent phase of geminates, in *absolute* values, are significantly longer than corresponding singletons, for all consonants (alveolars, velars and uvulars), and in both the voiced and voiceless contexts, for all six subjects, in the two speech rate conditions. This result is in line with *hypothesis 1*. This hypothesis is further consolidated as durational differences between geminates and singletons are maintained in fast speech, although consonantal closures undergo compression; this compression is more pronounced for geminates. It was noticed that consonantal gemination did not affect the duration of adjacent vowels V1 and V2, as expected, given statistical results reported *supra*. *Hypothesis 2* is consequently not verified. Likewise for intrasegmental VTT and VOT values which are also similar for both categories (*hypothesis 3*). The *acoustic data* further show that consonantal closure and the occlusion/silent phase of geminates, in *relative* values take up a higher proportion of the CV domain ($p<0.0001$), compared with their singleton counterparts, thus highlighting the robustness of the phonological distinction, regardless of compression induced by increased speaking rate. Proportions remain relatively stable in fast speech, as they are comparable in this speaking condition for geminates and for singletons.

Articulatory results given here are based on raw data, and rarely on statistics, due to experimental conditions (exposure to X-rays). Some of them should therefore be considered as tendencies. Measurements obtained from mid sagittal profiles show, for plosives, that contact-extents (maximum value for contact) are longer for geminate consonants than for their singleton counterparts. Figure 1a shows contact-extent (frames 187 and 188) for the apical singleton, accompanied by a concomitant enlargement of the pharynx. It can be seen that, conversely, while constriction opening is large in the alveolar region for the flanking /a/ vowels (frames 183 to 186, then frames 190 to 191), pharyngeal constriction is maintained for these vowels. The scenario is structurally similar for the geminate plosive (Figure 1b), but contact-extent is remarkably longer (frames 633 to 636). Hence tongue-palate contact perturbs the size of pharyngeal constriction only during occlusion, and not when vocal tract configurations, associated to the production of the vowels, emerge. Constriction opening in the critical pharyngeal region for vowel /a/ does not vary as a function of any coarticulatory influence from the consonant and this is seemingly why no shortening of the adjacent vowels by geminates was observed on the acoustic level (*hypothesis 5* not confirmed). These observations are valid, in an intra-speaker pair-wise comparison, for all the linguistic categories examined *i.e.* alveolars, velars and uvulars, for voiced and voiceless consonants, for fricatives (based on noticeable differences of constriction length, see Figures 2a and 2b) and for the two speakers (thus corroborating *hypothesis 4*). The constriction duration differences are maintained for all positions, including word-initial and –final positions (see Figure 3a and 3b for final t/tt contrast).

4. CONCLUSIONS

A close look at both the articulatory and the acoustic data suggests that all speakers adopt comparable strategies in contrasting singletons and geminates. Specifically, it is shown that the most systematic acoustic and articulatory correlate distinguishing Tarifit Berber singletons from geminates is consonant duration. This difference holds for all types of obstruents in all word positions, including word-initial and word-final voiceless stops, and operates at a normal as well as at a fast speaking rate. The phonetic characteristics of Tarifit geminates may be captured from a phonological standpoint by a structural representation of these segments as two timing units associated with one segmental slot, the relevant timing measure being the duration of the consonant (and closure duration for stops)

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Figure 1 a and b: *Frame-by-frame analyses of tongue gestures during the production of the apical singleton /t/ (Figure 1a) vs. geminate /tt/ (Figure 1b), in intervocalic position. Speaker F. See text for explanation*

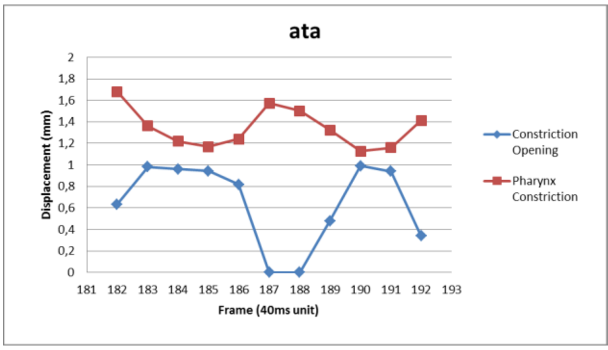

Figure 1a

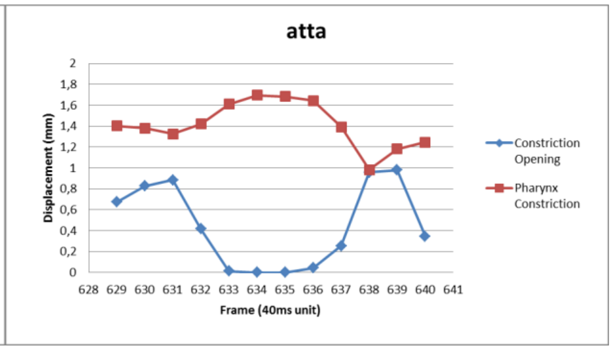

Figure 1b

Figure 2 a and b: *Frame-by-frame analyses of tongue gestures during the production of the apical singleton /s/ (Figure 2a) vs. geminate /ss/ (Figure 2b), in intervocalic position. Speaker F.*

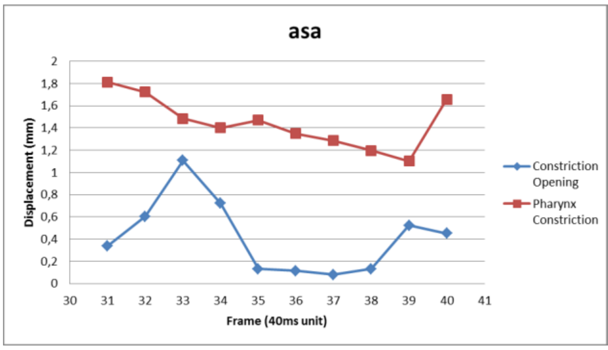

Figure 2a

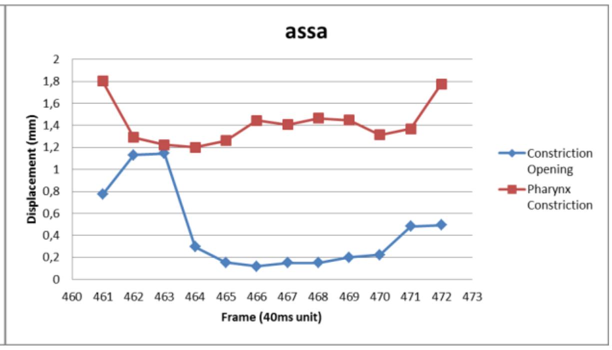

Figure 2b

Figure 3 a and b: *Frame-by-frame analyses of tongue gestures during the production of the apical singleton /t/ (Figure 3a) vs. geminate /tt/ (Figure 3b), in word final position. Speaker F.*

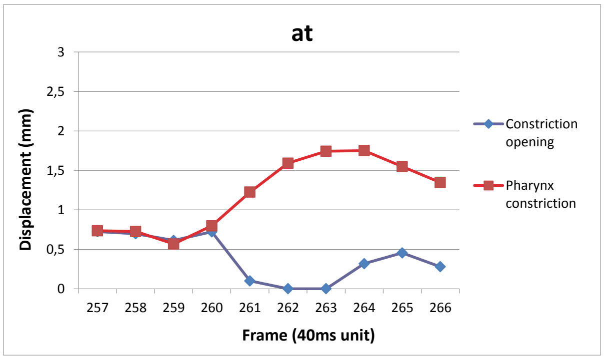

Figure 3a

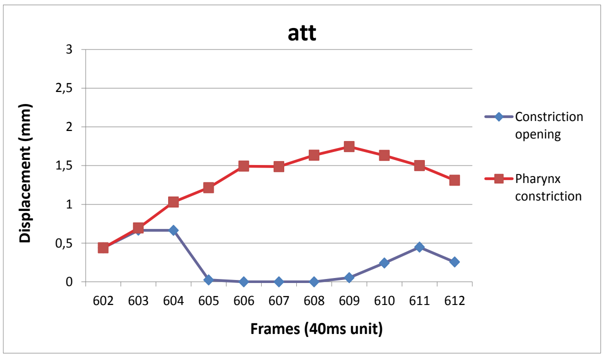

Figure 3b