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The timing of geminate consonants in Tarifit Berber

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Abstract--The main thrust of this investigation is to examine timing of gemination in Tarifit Berber (spoken in Northern Morocco) in order to find out if spatiotemporal phonetic characteristics underlying the production of Tarifit geminates may be captured from a phonological standpoint by a structural representation of these segments as two consecutive timing units associated with one simultaneous segmental slot. The investigation is based on acoustic data for six native speakers and on X-ray data for two native speakers. It presents results 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.

Key-words: gemination, tarifit berber, acoustic study, articulatory study, X-ray data.

I. THE PROBLEM

On the acoustic level, several studies (see e.g. [1] and [5]) have been conducted in different languages with singleton / geminate distinction in order to identify acoustic cues which may underlie this phonological distinction. Hence a set of parameters have been examined such as the duration of the adjacent vowels, duration of occlusion, duration of VOT, the duration of fricatives, the amplitude of the burst and the fundamental frequency of the following vowel. These authors identified several cues that distinguish singletons from geminates. Most of these studies found that the duration of the consonantal closure was the principal cue in distinguishing the two main categories.

On the articulatory level, several works (see e.g. [9], [6], [4] and [2]) have been conducted on different languages with the singleton / geminate distinction so as to determine the articulatory cues responsible for this contrast. Different methods have been used to observe the phenomenon of gemination on both glottal and supraglottal levels.

Within the perturbation paradigm, some studies have examined singleton and geminate consonants on the acoustic and articulatory level, varying speech rate (see [3], [7] and [9]). The objective was mainly to determine the impact of speech rate on these consonants: the compressibility, incompressibility of some categories and the robustness of geminates with increased speaking rate.

In this study, we present results of an investigation on the acoustic and articulatory correlates that may purportedly distinguish singleton stops and fricatives from their geminate counterparts in three positions: word-initial, word-medial, and word-final. Our aim is also to determine whether position in the word shapes variability in singleton/geminate contrast. In addition, we varied speech rate in order to find out whether the geminate contrast is resistant to increased speaking rate.

II. HYPOTHESES

It is hypothesised on the acoustic level that: (1) geminates would have longer closure durations than singletons as reported in the literature. (2) The duration of flanking vowels may be affected by that of geminate consonants; they would be shorter in this environment in case of syllable isochrony. (3) Acoustic silence for voiceless stops and (4) consonantal occlusion for voiceless stops, two intrasegmental consonant intervals, should underlie this phonological contrast as a gauge of potentially reinforcing the main cue of consonantal closure. (5) 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. (6) It is likely that VTT (Voice Termination Times) would be longer for singletons than for geminates. Indeed, the shorter the consonantal closure, the higher the proportion of voicing decay within this consonantal closure would be. (7) The speech signal is intrinsically elastic; all segments are expected to undergo compression with increasing speaking rate. This compression of the speech signal should, however, not prevent preservation of phonological contrasts.

On the articulatory level, (8) 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. (9) The differences of duration between singleton and geminate consonants observed acoustically should also be visible primarily in the temporal control of articulatory parameters. (10) These durational differences could be accompanied by differences in critical articulator displacements, hence in the spatial dimension. (11) Spatiotemporal differences between the two speakers could be observed in this
investigation, if one takes into account factors usually related to specific-speaker differences. (12) We shall
examine the phenomena of anticipation. Assuming potentially longer gestures for geminates, it would be
necessary to anticipate critical parameters underlying them earlier. As a corollary, it is likely that the onset of
post-consonantal vocalic gesture would be: (a) delayed in the context of geminates, the time to properly obtain a
sufficiently long contact or constriction and (b) anticipated in the context of singletons, where contact
would require relatively less time. (13) At the glottal
level, the difference between singletons and geminates
would be the same as that between the production of
implosive and ejective consonants. The set larynx-hyoid
bone position should be higher for geminates, as for
ejectives, due to the rate of intraoral pressure which is
usually higher for geminates.

III. METHOD

The entire corpus (voiced and voiceless plosives for
apicals /t, d/, for velars /k, g/, for the uvular /q/, and
voiced and voiceless fricatives for alveolars /s, z/, for
postalveolars /f, ʃ/) consisted of 54 sentences of 4 to 6
syllables, comprising 27 minimal pairs that were
inserted in meaningful carrier sentences, pronounced 10
times by six native speakers of Tarifit, at normal and
fast speaking rates.

All X-ray data were extracted from the Phonetics
Institute of Strasbourg database [8]. In this X-ray
experiment (25 frames /sec), these minimal pairs were
produced once at a normal (self-selected) speaking rate
by two speakers.

The X-articulator software, developed at LORIA in
Nancy within the DOCVACIM project [8], 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 the contours, and also tools
devoted to data analyses and elaboration of articulatory
models.

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,
geminate 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 voiced 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. Hence these intrasegmental durations,
which only concerned plosives, were embedded within
the consonantal closure duration of the plosive.

All acoustic measurements, extracted automatically
using the software PRAAT, were analysed using the
GraphPad Prism® software.

The first question regarding the distribution of
singleton and geminate consonants was to find out if
both length categories behaved in a similar way with
variation of speech rate. To do so, a pair-by-pair comparison (T-test) was conducted between singleton
and geminate pairs, at each speech rate, and between
singletons and geminates in the two speech rate
conditions. The variance is given with the f and df
factors, as well as the significance of the difference of
compared data with the p value.

We also analysed interactions between gemination
and speech rate. Thus a two-factor ANOVA was
conducted by considering the average of 10 repetitions
of each speaker as an unpaired repetition and as two
analysed factors: gemination and speech rate. For the
ANOVA analyses, we give the variance data with the F
ratio, corresponding to variability between subjects, and
the p value.

In addition to the two-factor ANOVA analyses, we
also carried out a T-test between the duration of the
singletons in normal speech and the geminates in fast
speech.

Only results with a probability of less than five
percent (p <0.05) were considered significant and
reported infra (statistical details are provides in [2]).

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, and in both the voiced
and voiceless contexts, for all six subjects, in the two
speech rate conditions (see Figure 1). Thus, apart from
geminate closures, acoustic silence for voiceless
stops and consonantal occlusion for voiceless stops, two
intrasegmental consonant intervals, do underlie this
phonological contrast of gemination. These findings are
in line with hypotheses 1, 3 and 4 respectively. These
durational differences between geminates and
singletons are maintained in fast speech (Figure 1, on
the right), thus confirming hypothesis 7 in absolute
terms. However, if all consonantal closures undergo
compression, compression is more pronounced in
geminates than in singletons. Indeed, segmental
elasticity is usually more prominent in longer
phonological entities [3], [9]. It was noticed that
geminate occlusion did not affect the duration of
adjacent vowels V1 and V2, contrary to our
expectations (hypothesis 2). Likewise for
intrasegmental VOT and VTT values, which are also
similar for both categories (Figure 2), thus in
contradiction with hypotheses 5 and 6, respectively.

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 (Figure 3), thus underpinning 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 (hypothesis 7 is verified in

IV. RESULTS
relative terms). Therefore, relative stability seems to be the major timing maneuver deployed in preserving phonological distinctions. Position in the word does not seem to shape variability in the singleton/geminate contrast, hence reinforcing the relevance and the robustness of gemination in Tarifit Berber.

Results concerning the consonants highlighted in this paper can indeed be generalised to all other consonants examined in a longer investigation (see [2]).

Articulatory results given here are based on raw data due to the relatively low quantity of available X-ray data.

Measurements obtained from mid sagittal profiles show, for plosives, that contact-extends (maximum value for contact) are larger for geminate consonant stops than for their singleton counterparts (Figure 4). This observation also applies to fricatives, where maximum constriction length is higher for geminates (as conjectured in hypotheses 8 and 9 respectively). Indeed, these two spatial parameters seem to partly underlie a critical acoustic temporal cue for gemination, *i.e.* acoustic consonantal closure. It is also worthwhile mentioning that contact-extend increases from alveolar, to velar (rather palatal here), and then to uvular consonants (with a few exceptions in the latter case). The articulatory duration of geminate consonants (constriction opening or *articulatory closure*, in ms) is longer than that of their singleton counterparts (Figure 5), as was observed in the acoustic level. These differences of durations are accompanied by differences in the duration of critical articulator positions (pharynx constriction and lip aperture, in ms), *i.e.* in the spatiotemporal dimension, as predicted in hypothesis 10.

Considering relations between articulatory parameters, the data show a sort of basic preassigned values for plosives: longer articulatory closures have longer contact-extends, and *vice versa*.

Looking at articulatory-acoustic relations, we note that the combination of contact-extend and the acoustic duration of consonants allows more clear-cut distinctions in the terms of contrasting the two phonological categories. Examination of the data reveals that when two temporal parameters are combined, *i.e.* articulatory consonantal closure and acoustic consonantal closure, they have a notorious power to clearly distinguish the two phonological categories, for both voiceless and voiced consonantal, and as much as for plosives as for fricatives. The phonological phenomenon of gemination decidedly relies primarily on a temporal physical substrate.

Although minor spatiotemporal differences between the two speakers were observed in this investigation, however, no remarkable speaker-specific strategies were seen in the production of the phonological contrast (not as expected following hypothesis 11). One may therefore say that gestural control is quite constrained by phonological requirements for maintaining the distinctive feature.

In producing geminates, both speakers precociously anticipate critical parameters underlying the emergence of the target consonants (Figure 5, on the right). Hence, onsets for constriction opening, pharynx constriction and lip aperture are initiated in vocal tract configurations corresponding to onset of the preceding vowel /a/ (frame 631). Similarly, onset of post-consonantal vocalic gestures (constriction opening, pharynx constriction and lip aperture) are indeed delayed in the context of these geminates, thus obtaining sufficiently and desired long contacts or constrictions for such consonants (frame 636). As regards the production of singletons, the abovementioned anticipatory gestures are observed only within /a/ vocal tract configurations, *i.e.* comparatively later than for geminates (Figure 5 on the left, frame 186). The post-consonantal vocalic gestures, in the case of singletons, are not delayed as was the case for geminates, but well anticipated in this context (frame 188), where contacts or constrictions do seem to require relatively less time for their acoustic emergence. Such findings generally corroborate our initial predictions relating to anticipatory behaviour (hypothesis 12).

The position of the larynx-hyoid bone couple (Figure 6) is comparable for both terms of the phonological contrast. Therefore, producing geminate consonants, which usually implies high intraoral pressure, did not show any positive correlation between increased sub-glottal pressure for geminates and vertical elevation of the larynx-hyoid bone couple (contrary to hypothesis 13). Future investigations might need to rather focus on physiological data and vocal fold activity in order to underpin potential differences in the production of the two phonological categories.

V. 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 the three word positions, including word-initial and word-final voiceless stops, and operates at a normal as well as at a fast speaking rate.

It is in within a perspective of articulatory-acoustic relations that we propose to treat the phonological phenomenon of gemination in Tarifit as follows:

1) Singletons in Tarifit would correspond to: a) a single gesture with its specific spatiotemporal organisation, *i.e.* one supraglottal occlusion / constriction of a certain duration, accompanied by a contact-extend of a given width; b) an acoustic consonantal closure, reinforced by an acoustic silent phase or by an acoustic occlusion of specific durations.

2) Geminates would correspond to: a) a single gesture comparable to that of its singleton counterpart, but having a supraglottal occlusion / constriction of a duration greater than that of the singleton, accompanied by a contact-extend also larger than that of the singleton; b) an acoustic consonant consonantal closure, reinforced by an acoustic silent phase or by an acoustic occlusion with durations higher than those of the singleton.
counterparts.

Thus, Tarifit geminate plosives (and constrictives) would be “shaped” from their singleton counterparts, the speaker having learned to trigger adequate articulatory and acoustic spatiotemporal reorganisations in going from one entity to the other. Indeed, according to our articulatory and acoustic data, the speaker would be doing the same thing once, but for a longer time lapse (“doing the same thing once, for a longer period of time”; see [2, 7 & 9]), since for plosives: 1) spatiotemporal articulatory patterns are structurally comparable between singletons and geminates; 2) only a single and prolonged contact was observed for geminates; 3) the nature of this contact is qualitatively but not quantitatively similar to that of singletons; 4) the acoustic signal, therefore, reveals no rupture, neither in the silent phase of voiceless consonantal closures, nor in that of the consonantal occlusion of voiced consonants.

Hence gemination in Tarifit would be, among others, a phenomenon of temporal rescaling of phasing patterns and of reorganisation of a critical spatial parameter.

Some of these phonetic characteristics of Tarifit geminates may be captured, from a phonological standpoint, by a structural representation of these segments as two consecutive timing units associated with one simultaneous segmental slot, the most relevant timing measure being the duration of the consonant. This point of view will be taken up in detail in a forthcoming investigation.

VI. REFERENCES


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Figure 1: Duration (ms) of intersegmental parameters of singleton and geminate voiceless stops in intervocalic positions, at normal (left) and fast speaking rates (right). See text for details.
Figure 2: Duration (ms) of intrasegmental parameters of singleton and geminate voiceless stops in intervocalic positions, at normal (left) and fast speaking rates (right). See text for details.

Figure 3: Relative values C/CV of /t/ vs. /tt/ (left) and /k/ vs. /kk/ (right) in fast and normal speaking rates in intervocalic positions. See text for details.

Figure 4: Contact extent of /t/ (left = 5 mm) and /tt/ (right = 11 mm); speaker F
Figure 5: Trajectory of three articulatory parameters (constriction opening, pharynx constriction and lip aperture) of /ata/ (left) and /atta/ (right); speaker F.

Figure 6: Trajectory of two articulatory parameters (larynx position and hyoid bone position) of /ata/ (left) and /atta/ (right); speaker F.