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Acoustic cues to the singleton-geminate contrast: the case of Libyan Arabic sonorants

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Abstract

This study examines the acoustic correlates of the singleton and geminate consonants in Tripolitanian Libyan Arabic (TLA). Several measurements were obtained including target segment duration, preceding vowel duration, RMS amplitude for the singleton and geminate consonants, and F1, F2 and F3 for the target consonants. The results confirm that the primary acoustic correlate that distinguishes singletons from geminates in TLA is duration regardless of sound type with the ratio of C to CC being 1 to 2.42. The duration of the preceding vowels is suggestive and may be considered as another cue to the distinction between them. There was no evidence of differences in RMS amplitude between singleton and geminate consonants of any type. F1, F2 and F3 frequencies are found to show similar patterns for singleton and geminate consonants for all sound types, suggesting no gestural effects of gemination in TLA. Preliminary results from the phonetic cues investigated here suggest that the acoustic distinction between singleton and geminate consonants in TLA is dependent mainly on durational correlates.

Index Terms: Arabic, gemination, sonorant sounds, acoustic correlates, duration, RMS amplitude, Formant frequencies.

1. Introduction

Traditionally, durational cues to gemination have formed the main emphasis in investigating the singleton-geminate contrast and, generally, these studies in various languages have shown that duration is the most robust correlate of gemination (see e.g. [1] and [2], among others). However, some studies have suggested that other non-durational correlates of geminates exist, and argued that these characteristics contribute to the perceptual effect of gemination. These include, for example, a palatalized configuration for geminate sonorants [3] and geminate laterals [4], more lenited stops in singleton contexts [5], higher root mean square (RMS) amplitude for geminate stop release [5], and differences in the quality of the sonorant geminates as opposed to their singleton counterparts, while geminates appear to affect the duration and quality of preceding segments as well [6].

Some researchers argue that some of these cues are suggestive of a tense/lax distinction between singleton and geminate consonants alongside durational contrasts (see e.g. [7] and [5]). Although these non-temporal cues are found to be salient for some languages, the results of these studies are not consistent across languages. For instance, [8] report evidence from several types of measurements that non-durational cues to gemination do not exist in Cypriot Greek.

While consonant gemination in TLA is very frequent and play an important role in the grammar of the language, very little is known about the phonetic realisation of gemination in this dialect [9], with the non-durational acoustic cues to the singleton-geminate contrast have not been investigated yet. In this study, the intervocalic word-medial singletons and lexical 'true' geminates will be investigated acoustically. While most of the previous phonetic studies on Arabic gemination have focused on the durational cues of the singleton-geminate contrast, this study looks at a variety of non-durational correlates as well as durational ones. This study contributes to the literature on gemination and the literature on Arabic language by providing a detailed investigation of both the durational and non-durational acoustic correlates of the singleton and geminate consonants in TLA using sonorant sounds.

2. Method

2.1. Speakers

Four native speakers (3 males, 1 female) of TLA, a dialect of Arabic spoken in the North-West region of Libya (Tripolitania province), were recruited. They ranged in age, at the time of recording, from 30 to 38 years, and had no obvious speech or hearing defects.

2.2. Stimuli and data Recording

Trisyllabic minimal or near minimal words containing the sonorant sounds /l, m, n, r/ were considered. The speakers were recorded reading word-lists containing word-medial intervocalic singleton and geminate consonants preceded by short and long vowels. The spelling and diacritics of the words followed the TLA regional pronunciation.

Each one of the four speakers was asked to read a list composed of 66 tokens (16 randomized words x 3 repetitions + 6 filler words x 3 repetitions). Each target word was produced in the carrier sentence [gæ:l aħmid ________ tæ:ni] "Ahmed said ________ again". The tokens were extracted from the list each into a separate wavfile for auditory and acoustic analysis.

2.3. Measurements and Statistics

Duration measurement (in millisecond) of the singleton and geminate consonants, and the preceding vowels were made

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using PRAAT [10]. The data were labelled semi-automatically using Praat annotation text grids relying on both the spectrogram and the corresponding waveform. The durational measurements were obtained using a script and checked by hand. Additional measurements where obtained automatically using specifically designed scripts. The acoustic measurements conducted in this study include the following:

- The duration of the target consonants
- The duration of the preceding vowels
- RMS amplitude of the target consonants
- F1, F2, and F3 of the target consonants

An oral constriction criterion [11] is used to segment all the target speech sounds. In this method, the onset and release of oral consonantal constriction is used to identify the sound boundaries. RMS amplitude was measured over the duration of the target segments in decibel (dB). The RMS values were normalized by dividing its value by that of the preceding vowel. F1, F2, and F3 were measured at the midpoint of the target consonant.

The results are based on a series of independent analysis of variance (ANOVAs) and independent T-tests.

3. Results

3.1. Target segment duration

ANOVA reveals that the durational differences between singletons and lexical geminates are significant ($F(1,3)=91.837$, $p<0.001$), sound category is significant ($F(3,8)=4.009$, $p<0.05$), and speaker is not significant ($F(3,6)=0.072$, $p=0.973$). The interaction between the singleton-geminate contrast and sound category is not significant ($F(3,9)=1.313$, $p=0.329$). This reflects that duration plays a significant role in the phonemic contrast between singleton and geminate consonants in TLA with the ratio of C to CC (singletons to geminates) being 1 to 2.42. See Figure 1 for mean duration and standard deviation of singleton and geminate consonants for each of the four sounds.

As Figure 1 shows, in both C and CC contexts the shortest consonants are rhotics followed by the alveolar nasals and the laterals (which show similar durational patterns), with the bilabial nasal being the longest. It has been noticed from the data that the alveolar rhotics show manner variation within and across speakers. The singleton /r/ is realised as a tap or approximant. The geminate /r/ is realised as approximant, trill or weak fricative.

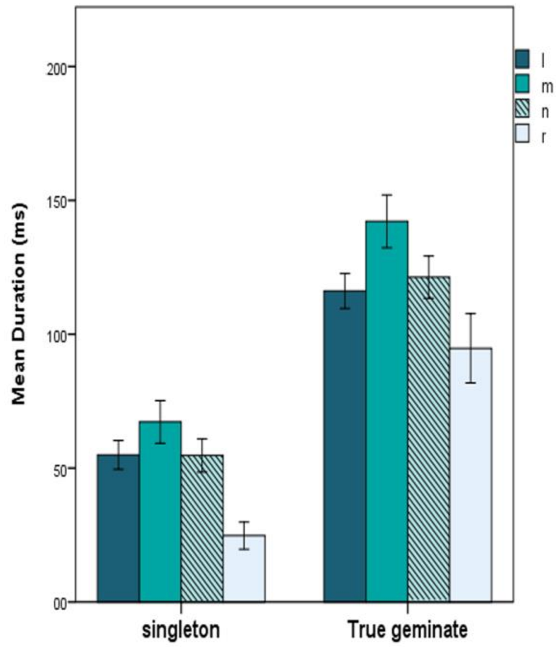

Figure 1: *Mean duration (in ms) and standard deviation of each of the consonant categories in singleton and geminate targets.*

3.2. Preceding vowel

There is a significant difference between the durational results of the preceding short vowel in the context of singleton and geminate consonants. That is, gemination significantly shortens preceding short vowels ($t = 10.157$, $p<0.001$). On the contrary, the durational values for long vowels preceding singleton consonants are not significantly different from those preceding geminate consonants ($t = -0.445$, $p=.659$). See Table1 and Table 2 for consonant and vowel durations and the ratio of C to CC and V to VV in the singleton and geminate contexts.

Table 1: *Mean duration (in ms) and standard deviation for vowels and consonants in medial VC, VCC, VVC, and VVCC contexts, and ratio of C to CC in short and long vowel contexts.*

Context	**VC**		**VCC**		**V VC**		**V VCC**	
Segment	**V**	**C**	**V**	**CC**	**VV**	**C**	**VV**	**CC**
Mean	87.6	38.3	50.9	116.1	101.2	67.1	103.6	136.3
SD	30	21.8	14	23	22.1	17.7	26.3	24.2
Ratio of C to CC	**1 : 3.03**				**1 : 2.03**			

Table 2: *Ratio of V to VV in singleton and geminate contexts.*

Ratio of V to VV		
Consonant context	C contexts	CC contexts
Ratio of V to VV	1: 1.15	1 :2.03

Looking at consonant duration first, geminate consonants are predictably longer than singleton consonants regardless of the quantity of the preceding vowel. As Table 1 shows, the ratio of C to CC is around 1 to 3 when preceded by a short vowel and 1 to 2 when preceded by a long vowel. This seems to be due to V duration being significantly shorter before geminate consonants than before singleton ones and VV duration being not significantly different in these two contexts. This is reflected in the ratio of V to VV presented in Table 2 where the ratio of V to VV is 1 to 1.15 in the context of C and about 1 to 2 in the context of CC.

3.3. Target segment RMS

ANOVA shows that the difference in RMS amplitude between singletons and geminates is not significant (F(1,3)=0.186, p=0.806). The sound category and speaker has no effects (F(3,06)=27.014, p<0.05). The interactions between the singleton-geminate contrast and sound category (F(2,6)=0,148, p=0.871) and singleton-geminate contrast and speaker (F(3,6)=0.324, p=0.809) are also not significant. The interaction between the three factors is significant (F(6,95)=3,061, p<0.05). This reflects a consistency in the RMS values for the four sounds across speakers. Figure 2 shows the RMS results for the singleton and geminate consonants.

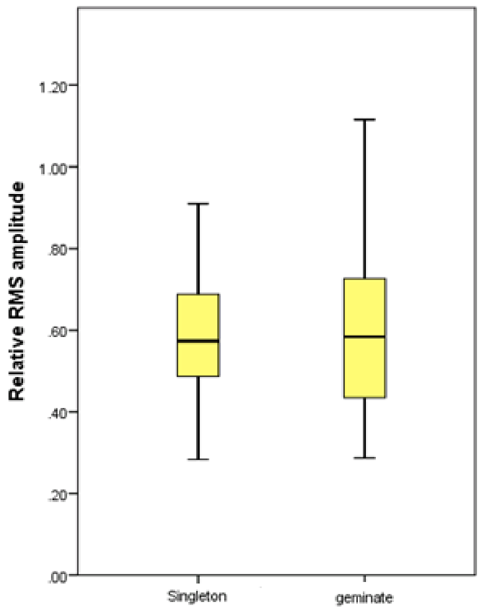

Figure 2: *Relative RMS amplitude values for singleton and geminate consonants.*

3.4. Target segment Formant frequencies

The extracted F1, F2, and F3 values were analysed in factorial ANOVAs each separately to test the singleton-geminate contrast. As Figure 3 shows, it is clear that the general tendency indicates that a geminate consonant has no effect on the formant structure of the target segments in TLA.

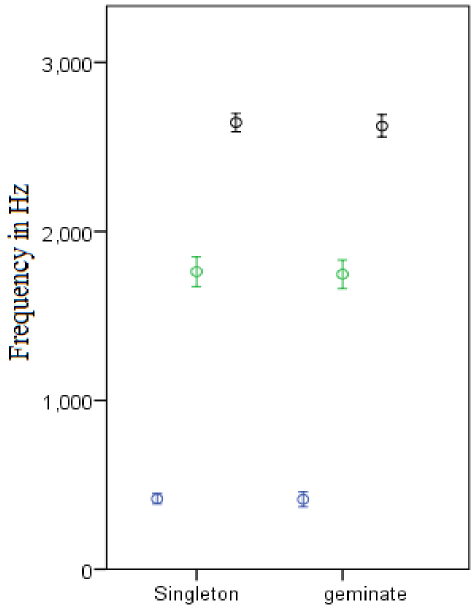

Figure 3: *R Mean frequency (in Hz) of F1, F2 and F3 in singleton and geminate contexts.*

F1 does not contribute to the singleton-geminate contrast (F(3,5)=0.038, p=0.989). The sound category (F(3,10)=2.268, p=0.141) and speaker (F(3,7)=0.209, p=0.887) has no effects. Post hoc LSD test also fails to show any significant differences between the levels of these factors.

No significant differences could be found for F2 between singleton and geminate consonants (F(3,2)=0.798, p=0.584). The sound category is not significant (F(3,8)=1.077, p=0.408), and the speaker is not significant (F(3,8)=2.630, p=0.116). Post hoc LSD test also failed to show any significant differences between any of the levels tested. This result suggests that the structure of F2 is consistent across the singletons and geminates regardless of sound type and speaker, which indicates that gemination has no effect on F2.

F3 has no effect on the singleton-geminate contrast (F(3,1.7)=1.099, p=0.522). The sound category is significant (F(3,8)=5.389, p=0.022), and the speaker is significant (F(3,5)=14.075, p=0.006). This significant effect of the sound category is resulting from F3 frequencies for the alveolar lateral /l/ that are considerably higher (around 2700 Hz for singletons and 3000Hz for geminates) than F3 for the other sound types. A deeper look at the data revealed that the significant effect of the speaker factor is resulting from the higher F3 frequencies of the female speaker compared to that of the male speakers. F3 is higher for the female speaker for all singletons and geminates (around 2900-3000 Hz) across all sound types compared to male speakers (around 2500-2600 Hz), which is expected as an effect of gender on Formant frequencies. However, this gender effect is not present in the analysis of F1 and F2. Post hoc LSD tests failed to show any significant differences between any of the levels tested, which confirms that the significant sound and speaker effects found here do not result from differences between singleton and geminate consonants. That is, gemination has no effect on F3 regardless of sound type and speaker.

4. Discussion and Conclusion

This paper has presented evidence from several types of measurements on the acoustics of geminate consonants in TLA. The results emphasize the significant role of duration as consistent and robust cue to gemination for all types of sounds involved. Additionally, this study presents evidence that the duration of the preceding vowels is possibly another cue to the distinction between singleton and geminate consonants in TLA, with only short vowels showing temporal compensation. In addition to the duration of the target segments themselves and to their possible effect on the preceding vowels, other types of evidence relating to the acoustic characteristics of geminates have been investigated here. I was prompted to undertake this investigation because of the findings, reported for some languages, that gemination may indeed involve several acoustic parameters in addition to duration ([6], [12], [7]).

However, neither of these proposals has been supported by the data from this study. There were no differences in RMS amplitude between singletons and geminates. I argue here that the higher amplitude of geminates reported in the literature might be considered as a concomitant correlate of manner of articulation and not to phonological length of these long segments. This can be supported by the fact that in the studies where RMS differences have been found to be significant, the analysis was dependent on results from geminate stops (see [13] and [12]), and in case of geminate stop, high RMS amplitude is predictable due to the manner of articulation. On the contrary, in this study, where approximants are used, since there is no high air pressure build up (as a result of closure as in the case of stops), no RMS amplitude differences can be found. This interpretation needs further investigation, and future research should continue to investigate the interrelationships among the manner of articulating geminates and RMS amplitude.

Formant frequencies of the target consonants at the mid-point were used in this study to evaluate potential qualitative differences linked with the singleton-geminate contrast. The formant analysis was used by some researchers to test for the presence of gestural differences between geminates and non-geminates. [4] found evidence of lower F1 and higher F2 and F3 (measured at mid-point) for the geminate /l:/ in Italian. She interpreted this finding as a more palatalised configuration for the geminate /l:/ than for /l/, suggesting differences in gestural configurations between singleton and geminate laterals that are present in the consonant segment itself. [6] also found evidence of lower F1 and higher F2 (at mid-point) for geminate laterals in Malayalam. Their result was robust throughout the dataset. They interpreted this as clearer (more palatalised) resonance for geminates. They suggest that geminate consonants in Malayalam are produced with relative frontness and that non-geminates are darker in resonance than geminates irrespective of their place or manner of articulation based on both the formant analysis results and an impressionistic analysis. The results of these studies suggest that gemination has non-temporal gestural effects on the consonant sounds that is reflected in differences in the formant frequencies of these consonants. However, this proposal has not been supported by the data from the current study, which can indicate that the palatalization effect found is language-specific. No evidence could be found for the effect of gemination on the first three formants in TLA. The results of the current study provide evidence that the structure of F1, F2 and F3 is consistent across the singletons and geminates regardless of sound type, which suggests that gemination has no effect on the formant structure of sonorant sounds in TLA.

To sum up, this study provides evidence that duration plays a major role in discriminating the singleton-geminate contrast in TLA. The results from the phonetic cues investigated here suggest that the acoustic distinction between singleton and geminate consonants in TLA is dependent mainly on durational correlates and that non-durational acoustic cues do not contribute to this distinction. It is fair to say, however, that the results are based only on approximant sounds and further research involving other segment types will be necessary.

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