MULTIPLE CUES FOR THE SINGLETON-GEMINATE CONTRAST IN LEBANESE ARABIC: ACOUSTIC INVESTIGATION OF STOPS AND FRICATIVES

Jalal Al-Tamimi & Ghada Khattab

Newcastle University, UK
Jalal.Al-Tamimi@ncl.ac.uk; Ghada.Khattab@ncl.ac.uk

ABSTRACT

This paper investigates the role of temporal and non-temporal cues in the distinction between singleton and geminate medial consonants in Lebanese Arabic. Twenty male and female speakers were recorded producing a word-list with medial singleton and geminate voiced and voiceless stops and fricatives. Vowels preceding and following the medial consonant were /a/ or /aː/. A range of acoustic measures were applied on $V(V)_1$, $C(C)_2$ and V_2 including: absolute and relative durations (temporal); several Normalised-Intensity and *f*0 measures; $C(C)_2$ shape of spectrum and voicing patterns (non-temporal). Statistical analyses and classification rates were used to assess the contribution of each acoustic cue to the singleton-geminate contrast. Although temporal cues seem to play a major role in the singleton-geminate distinction, non-temporal cues had a considerable contribution (with mixed effect sizes). Our results confirm that the underlying contrast for gemination in Lebanese Arabic is temporal with Tense/Lax distinction as a secondary feature.

Keywords: germination, duration, spectral cues, Lebanese Arabic, articulatory strength

1. INTRODUCTION

The phonetic and phonological aspects of gemination have been the subject of investigation in various languages and different approaches to the representation and implementation of the singleton-geminate contrast have been proposed. From a phonological point of view, gemination refers to consonantal length contrast which interacts with language-specific timing, syllable structure, and (non-)contrastive vowel length [4]. From a phonetic point of view, the geminate/singleton distinction is thought to be a difference in “Articulatory Strength” ([10]) i.e. a fortis/lenis or tense/lax distinction ([12]), with obvious durational consequences. Fortis or tense consonants are produced with higher pulmonic strength and stronger articulation, leading to longer duration and less voicing compared to lenis or lax consonants ([7], [9]). However, whether durational differences observed in the geminate-singleton contrast are a by-product of “Articulatory Strength” or not is a contentious issue and seems to depend on the language in question.

Most research on Arabic has concentrated on temporal characteristics of gemination (e.g. [4], [6], [8]). In research on other languages, non-temporal characteristics have been proposed as secondary cues and are thought to enhance the perceptual distance between geminates and singletons (e.g. palatal configuration for coronal geminates ([11], [13]); lenited stops in singleton contexts ([14]); lower burst amplitude and occasional absence of bursts in singleton stops ([11], [14]).

This paper reports on the phonetic aspects of gemination in Lebanese Arabic (LA) and provides evidence for systematic qualitative differences between singleton and geminates consonants in a wide range of spectral and other non-temporal cues not looked at in combination before.

2. METHODOLOGY

2.1. Speakers and data recording

Twenty Lebanese males and females aged 18 to 40 were recorded producing randomised word-lists containing medial singleton and geminate stops and fricatives in four trochaic disyllabic structures: ˈ$C_1V_1C_2V_2C_3$, ˈ$C_1VV_1C_2V_2C_3$, ˈ$C_1V_1CC_2V_2C_3$ and ˈ$C_1VV_1CC_2V_2C_3$, where $C(C)_2$ was one of the following consonants: /b, t, tˤ, d, dˤ, k, ʔ, f, s, sˤ, z, ʃ, ʒ, x, ɣ, ħ, h/, and $V(V)_1$ and V_2 were either /a/ or /aː/. Recordings were made in a quiet room, using an R9 solid-state recorder with a Uni-directional condenser microphone, and digitised at 44.1 KHz, bin mono channel and 16-bit quantisation.

2.2. Acoustic analyses

Acoustic and auditory analyses were made using Praat ([1]). Acoustic measures applied on $V(V)_1C(C)_2V_2$ structure in 3722 tokens were:

- Absolute and relative Duration (as a function of the word and the $V(V)_1C(C)_2V_2$ syllable);
- Normalised-Intensity and *f*0 (mean for whole segment and at the onset, midpoint and offset);
- Shape of spectrum (four central moments and Peak) for the whole segment; onset, midpoint and offset (40ms window) and three thirds;
- Duration of voiced portions in $C(C)_2$.

2.3. Statistical analyses

Several 4-way MANOVAs and follow up ANOVAs were applied on Stops and Fricatives separately and on each of $V(V)_1$, $C(C)_2$ and V_2. The factors were: Gender; Syllable Structure; Place of Articulation, and Voicing. Dependent variables were acoustic measurements. Bonferroni Post-hoc analyses were performed to check for differences between low levels of each factor. For the MANOVA, the Wilks' Lambda (Λ) test is reported (with probability level symbolised as: ***=$p<.0001$; **=$p<.001$; *=$p<.01$). To evaluate the real contribution of each factor to the singleton-geminate contrast, we provide two effect size measures: the omega-squared measure (ω^2) for the factorial MANOVAs and ANOVAs, and Cohen's *d* for the Bonferroni post-hoc results [2]. Cohen's benchmarks are used to evaluate when an effect is "Small", "Moderate" or "High" (S, M and H hereafter) [2]. Several Discriminant Analyses were applied on the data, with the *leave-one-out* method for cross-validation. This was carried out to assess the degree of separation between singletons and geminates based on the different measurements.

2.4. Expectations

Based on previous findings from the literature, geminate environments were expected to have:

- Longer durations for CC_2 and potentially shorter duration for $V(V)_1$
- Higher Normalised-Intensity and *f*0
- Difference in shape of spectrum
- Reduced voicing

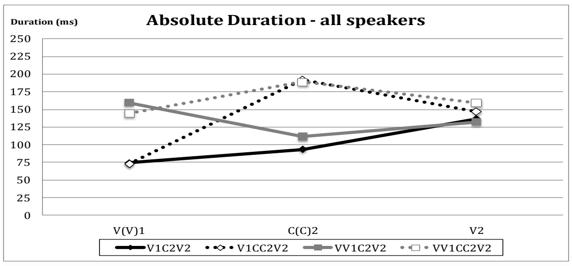
3. RESULTS

For all measurements (except in 3.3), Syllable Structure was the factor with the highest contribution to the singleton-geminate contrast across $V(V)_1$, $C(C)_2$ and V_2 (Wilks's $\Lambda<.2$, ***, $\omega^2>.8$(H)). In addition, no significant differences were observed for 3 and 4-way interactions indicating consistency between speakers; across places of articulation and voicing in the singleton-geminate contrast. Therefore, only results linked to Syllable Structure will be discussed.

3.1. Absolute and Relative Duration

For both fricatives and stops (only closure duration results (CD) are reported on here), longer absolute durations are observed for geminates compared to singletons with a very high effect size (CC_2 *vs.* C_2: ***, $d>.9$(H)), and moderately shorter VV_1 in geminate environments (VV_1CC_2 *vs.* VV_1C_2: **, $d<.5$(M)). V_2 results on the other hand showed longer durations in geminate environments with a small effect (**, $d<.4$(S-M)), (Fig. 1). The same results are observed for relative duration measures.

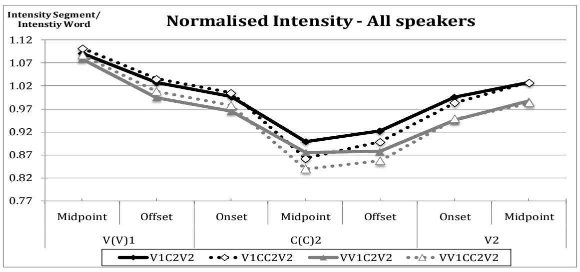
Figure 1: Absolute Duration for all speakers for $V(V)_1$, $C(C)_2$ and V_2, where plain lines indicate a singleton C_2 and dotted lines geminate CC_2 (the same display will be used throughout the article).



3.2. Normalised-Intensity and *f*0

For both fricatives and stops, high Normalised-Intensity with moderate effects are observed in geminate environments throughout $V(V)_1$ (***, $d<.4$(S-M)) and at the onset of CC_2 (***, $d<.3$(S)), followed by low values with small effects from the midpoint of CC_2 to the onset of V_2 (***, $d<.4$(S-M)) (Fig. 2). The same results are observed for *f*0 for males and females (cf. "image file 1").

Figure 2: Normalised Intensity for all speakers for $V(V)_1$, $C(C)_2$ and V_2.

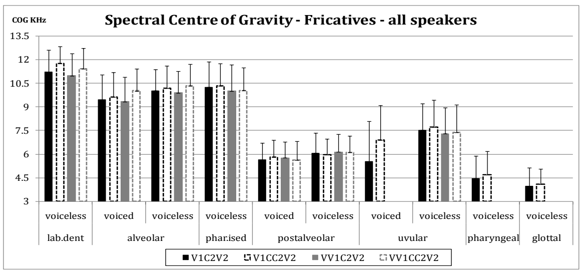


3.3. Quality of C(C)$_2$

Spectral moments were originally proposed by Forrest et al. [3] to pinpoint the place of articulation of fricatives and stops (with a connection between the Centre of Gravity and the size of the front cavity). We applied this method to evaluate any potential place of articulation differences in the singleton-geminate contrast. A low-pass filter (0-16KHz) and pre-emphasis were applied on the data. Several Kaiser-2 windows were used: whole duration of fricatives and stop CDs; 40ms window from the onset, around the midpoint and towards the offset; and whole duration/3 (three thirds). Then FFT spectrums were generated and the four central moments and the peak were obtained using Praat [1]. The same patterns were observed across the three portions.

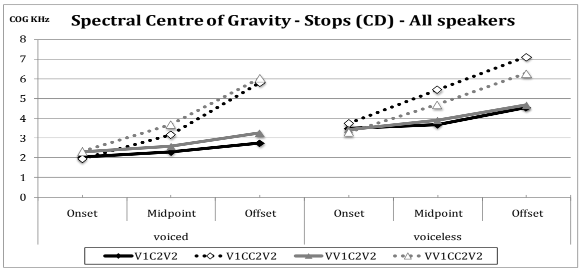
Our results for fricatives were consistent with the literature: place of articulation was the highest contributor to the MANOVA with front fricatives showing the highest Centre of Gravity frequencies and vice versa (Wilks's Λ <.2, ***, ω^2>.8). However, Syllable Structure showed interesting patterns across places of articulation (Fig. 3): relatively higher Centre of Gravity with small to moderate effects was obtained for geminates, except for postalveolars (values ranging between 54Hz and 1385Hz, ns-**, d<.03 to d<.6 (S-M)). Although statistical significance was not always reached, mean differences and effect size measures showed small variations that might be linked to potentially different places of articulation and/or part of the tongue used in producing singleton and geminate fricative consonants (cf. [5] for an example of possible change in place of articulation of coronal fricatives linked to differences in Centre of Gravity frequencies). These results suggested fronter articulation for geminate fricatives (back for postalveolars, stronger productions [10] and a possible high precision in "gestural target attainment" for fricatives [13].

Figure 3: Spectral Centre of Gravity for fricative consonants for onset, mid and offset portions.



For stops (Fig. 4), an interesting pattern emerged across all the places of articulation (cf. "image file 2"). At the onset, no significant differences were observed (ns, d<.01(S)). However, for the midpoint and mostly for the offset of the CD (i.e. before the stop release) a high Centre of Gravity and peak, a low Standard Deviation, Skewness and Kurtosis were observed in geminates (***, d>.7(M-H)). These results may be linked to the high pressure and "Articulatory Strength" suggested in the literature ([7], [9], [10]).

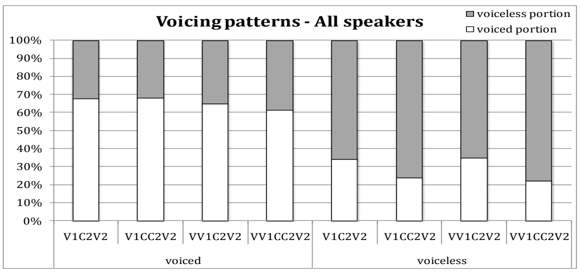
Figure 4: Spectral Centre of Gravity for stop consonants for onset, mid and offset portions.



3.4. Voicing patterns for C(C)$_2$

To quantify the duration of voiced and voiceless portions in fricatives and stops, low-pass filtering (0-500Hz) and pitch detection (autocorrelation; 5ms Gaussian window) were applied. We used Praat's [1] (VUV) function with a mean period duration adapted to each speaker. Then Voiced and Unvoiced frames were manually checked. No significant differences were observed for voiced stops and fricatives across places of articulation (ns, d<.1(S)) (Fig. 5). For voiceless stops and fricatives, however, results across places of articulation indicated systematically fewer voiced frames for geminates (***, d>.8(H)).

Figure 5: Voicing patterns for stops and fricatives for all speakers as a function of voicing.

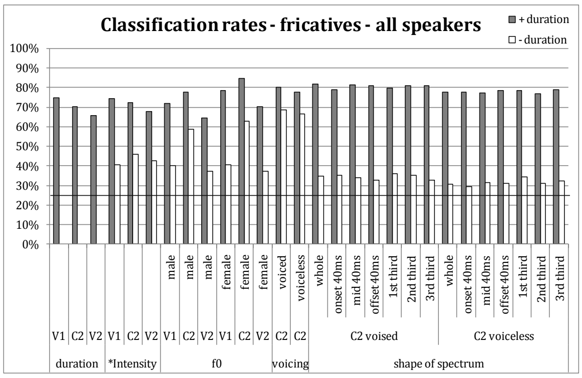


3.5. Discriminant Analyses

Discriminant Analyses were used to evaluate the degree to which each measurement contributed to the distinction between singletons and geminates.

Syllable Structure as a grouping factor was used. Higher classification rates indicated higher degree of separation between the groups because of highly significant differences and effect size measures. For non-temporal cues, duration was used as an additional predictor to assess its contribution. Classification rates for fricatives (Fig. 6) and for stops (cf. "image file 3") indicated a high degree of separation using duration alone (and in addition to non-temporal cues). This confirms the highly contributing role of duration to the separation between singletons and geminates, with non-temporal cues as secondary features.

Figure 6: Classification rates for $V(V)_1$, $C(C)_2$ and V_2, with duration included (in grey) and non included (white). The black line indicates significance limits.



4. DISCUSSION AND CONCLUSION

The aim of this study was to provide evidence for systematic qualitative differences for the singleton-geminate distinction in LA. As suggested in the literature on Arabic and other languages, duration was the main acoustic cue to the distinction between singleton and geminate medial consonants ([4], [6], [8], [14]). However, our results showed non-temporal cues being consistently used as a secondary feature. More particularly, *f*0 and Normalised-Intensity results showed a combined effect of stress, vowel quality and gemination; stressed geminate syllables with short /a/ vowels showed higher *f*0 and Normalised-Intensity patterns across V_1 and CC_2 onset than in singleton syllables preceded by /aː/ ([eː]). Voicing patterns highly contributed to the distinction between voiceless singleton and geminate consonants. The use of shape of spectrum opens a new dimension in the study of singleton-geminate contrast. These novel results suggest systematic qualitative differences that are not only conditioned by place of articulation. These results can be considered as a direct manifestation of "Articulatory Strength" [10], especially within stop CD: a rise in the Centre of Gravity frequencies might indicate a high level of pressure available before the release of stops. In fricatives, high Centre of Gravity suggests fronter articulation of geminates, stronger productions [10] and high precision in "gestural target attainment" [13]. Although these results suggest systematic qualitative differences, effect size measures and Discriminant Analyses results indicate that the singleton-geminate contrast in LA is mainly durational with secondary acoustic cues possibly leading to a Tense *vs.* lax distinction. Articulatory and perceptual data are needed to evaluate this.

5. ACKNOWLEDGEMENTS

This research was supported by an ESRC grant: RES-061-23-0053, and a British Academy grant.

6. REFERENCES

[1] Boersma, P. Weenink, D. 2009. *Praat: doing phonetics by computer* (Version 5.1.0) [Computer program]. Retrieved July 22, 2009, from *http://www.praat.org/*.

[2] Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

[3] Forrest, K., Weismer, G., Milenkovic, P., & Dougall, R. N. 1988. Statistical analysis of word-initial voiceless obstruents: Preliminary data. *J. Acoust. Soc. Am.* 84, 115-123.

[4] Ham, W. 2001. *Phonetic and phonological aspects of geminate timing*. New York: Routledge.

[5] Hamann, S. Heriberto, A. 2007. An acoustic study of plain and palatalized sibilants in Ocotepec Mixe. *Proc. 16th ICPhS*, Saarbrücken; 949-952.

[6] Hassan, Z. M. 2003. Temporal compensation between vowel and consonant in Swedish & Arabic in sequences of CV:C & CVC: and the word overall duration. *PHONUM*, 9: 45-48.

[7] Jaeger, J.J. 1983. The fortis/lenis question: evidence from Zapotec and Jawon. *J. Phon.*11, 177-189.

[8] Khattab, G. 2007. A phonetic study of gemination in Lebanese Arabic. *Proc. 16th ICPhS*, Saarbrücken, 153-158.

[9] Kodzasov, S. 1977. Fonetika Archinskogo Jazyka, part 2. In Kibrik, A. E., *Opyt Strukturnogo Opisanija Archinskogo Jazyka,* 1. Moscow: Izdatel'stvo Moskovskogo Universiteta.

[10] Kohler, K. 1984. The phonetic explanation in phonology: The feature fortis/lenis. *Phonetica* 41, 150-174.

[11] Local, J., Simpson A. 1999. Phonetic implementation of geminates in Malayalam nouns. *Proc. 14th ICPhS,* San Francisco, 1, 595-598.

[12] McKay, G. 1980. Medial stop gemination in Rembarrnga: a spectrographic study. *J. Phon.* 8, 343-352.

[13] Payne, E. 2006. Non-durational indices of gemination in Italian. *J. Inter. Phon. Assoc.* 36(1), 83-95.

[14] Ridouane, R. 2007. Gemination in Tashlhiyt Berber: an acoustic and articulatory study. *J. Inter. Phon. Assoc.* 37(2), 119-142.