Spectral properties of vowels preceding singleton and geminate consonants in Lebanese Arabic

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Vowel and consonant length play an important role in Lebanese Arabic (LA) phonology and morphology. All 26 consonants in LA can be geminated, and vowel length is also contrastive (Ham, 2001; Nasr, 1960). Medial geminates in LA can be preceded by both short and long vowels, leading to a 4-way contrast in terms of phonological length (/hakam/ 'referee'; /hakkam/ 'he treated'; /haakam/ 'he tried'; /haakka/ 'having scratched'). Consonant duration is major acoustic cue to the singleton *vs* geminate contrast in LA (Al-Tamimi and Khattab, 2011; Khattab, 2007), and the temporal relationship between the medial consonants and the preceding vowels has been shown to be supported by a moraic account of timing (Khattab and Al-Tamimi, 2014). This is manifested in the way phonologically short vowels show no change in duration when preceding singleton or geminate consonants, while both phonologically long vowels and the following geminate exhibit shortening due to mora sharing. This finding constitutes an interesting case of phonetic timing that does not follow the expected universal tendency for vowels to be shorter in closed than open syllable contexts; rather, it demonstrates that the phonetic implementation of consonant and vowel length is governed by language-specific phonological rules of segment timing and syllabic weight.

While our previous efforts have concentrated on temporal properties of the singleton-geminate contrast, in this study we explore the spectral properties of vowels preceding singleton and geminate consonants, with the aim to find out a) whether vowel quality differences are evident in the short vowel contexts regardless of the lack of durational differences; this would provide a window into VC(C) co-articulation, given that the consonants themselves have been shown to exhibit spectral and phonatory properties that are compatible with an overall tense or fortis articulation (Al-Tamimi and Khattab, forthcoming; Abramson, 1999; Idemaru and Guion, 2008; Local and Simpson, 1999; Payne, 2006, Ridouane, 2007 amongst others for similar results on other languages) and b) whether shortening in the long vowel context is accompanied by vowel reduction due to the shorter time available for vowels to reach their target. 20 speakers (10 men, 10 female) of LA with no reported history of speech disorders and aged between 18 and 40 were recruited from Beirut. All speakers were university-educated and were born and raised in Lebanon. The participants were recorded producing randomised word lists consisting of trochaic disyllables with medial singleton and geminate consonants preceded by phonologically short (/a/) and long (/a:/) target vowels followed by singleton or geminate consonants with various manners of articulation. Recordings were made in a quiet room, using an R9 solid-state recorder with a SONY MS957 Uni-directional Stereo Electret Condenser microphone (frequency response 50-18000 Hz), and digitized at 44.1 kHz, in mono channel and 16-bit quantization.

Acoustic and auditory analyses were done using Praat (Boersma and Weenink, 2009) and a script designed by the first author (following Al-Tamimi, 2007). Formant frequencies (F_1, F_2, F_3) of surrounding vowels were used to evaluate potential qualitative differences linked with the singleton vs geminate environments. These were obtained from a 25ms Gaussian window with a 5ms time step and interpolation. A maximum of five formants were requested in the formant analysis using the default Burg algorithm for formant estimation with a maximum frequency of 5 kHz for male and 5.5 kHz for female speakers. Then Praat's Formant track function was used in order to limit errors in automatic formant estimation. Formant frequencies were obtained at the midpoint and offset of the preceding vowel and at the onset and midpoint of the following vowel (not reported on here). Formant frequencies were then verified manually to prevent potential errors obtained from automatic extraction (errors constituted less than 5% of the data).

Starting with the short vowel context, there were no significant differences in F_1 or F_2 measures at the mid-point of the vowel preceding singleton and geminate consonants. At the offset however, both F_2 and F_3 showed significant differences, for both males and females. F_2 at the offset of the preceding vowel showed significantly lower frequencies in the singleton CVCVC compared to CVC:VC ($p<.002$, $d=-.28$). F_3 at the offset of the preceding vowel showed significantly lower frequencies in the singleton CVCVC context compared to CVC:VC ($p<.018$, $d=-.21$). Results obtained for the long preceding vowel context showed that F_1 frequencies at the midpoint were significantly lower in the singleton CV:CVC compared to CV:C:VC ($p<.0001$, $d=-.43$). F_2 frequencies obtained at the midpoint and offset of the preceding vowel

were significantly higher in the singleton CV:CVC compared to CV:C:VC ($p<.0001$, $d=.44$ and $p<.0001$, $d=.46$, respectively). The different effects exhibited on the long and short vowels preceding singleton and geminate consonants are interesting. The higher F2 at the offset of the short vowels preceding geminate consonants points to a move towards a more fronted articulation, potentially due to a palatalization effect from the consonant. Note that this is the context where vowels showed no shortening effect. On the other hand, the higher F1 and lower F2 for the long vowels preceding geminate consonants suggests a centralisation effect, which may be due to the vowel shortening in this context.

When looking at separate consonant categories, manner of articulation of the consonant played a role in the degree of effect seen on the spectral properties of vowels, with vowels preceding obstruents (stops and fricatives) showing little change in quality across the singleton-geminate contrast while vowels preceding sonorants (nasal, laterals and approximants) exhibited variable effects on F1 and F2. The higher perceptual salience of geminate obstruents (e.g. Podesva, 2002), rather than compensatory lengthening, may be responsible for the spectral changes in vowels preceding sonorant geminates. These and the above results suggest that spectral properties of vowels preceding singleton and geminate consonants exhibit different manifestations depending on their timing relations with the following consonant and the identity (manner) of that consonant. While a shortened vowel may show a centralisation effect which appears earlier in the articulation of the vowel, a stable vowel length may only show co-articulatory signs at its edges, with a more peripheral/tense articulation in preparation for the following geminate.

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