Effect of pharyngealisation on vowels revisited: Static and Dynamic analyses of vowels in Moroccan and Jordanian Arabic

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It is well known that, in Arabic, pharyngealisation affects following vowels by changing their quality: all the vowels become more open and more back when surrounded by pharyngealised consonants. Acoustically, higher values for F_1 and lower values for F_2 are obtained (see for example Ghazeli, 1977, 1981; Elgendy, 2001; Al-Tamimi and Barkat-Defradas, 2002, *inter alia*). By examining spectrograms, it is evident that pharyngealisation effects are visible on the whole structure of the vowel: i.e. mid-point, upper formants, formant transitions and onsets/offsets of each formant.

The aim of this work is to provide evidences of dialectal differences of pharyngealisation effects on following vowels in two Arabic dialects: Moroccan Arabic (MA, with a five vowel system /iː ə aː ʊ uː/ (Hamdi, 1991)) and Jordanian Arabic (JA, with an eight vowel system /iː i eː a aː oː u uː/ (Bani-Yassin and Owens, 1987)) and to examine effects of pharyngealisation on F_3, formant transitions and onsets of each formant. We are proposing to examine the vowels in these two dialects in terms of their static and dynamic properties. Static analysis consists of determining formant frequencies at the temporal mid-point which is considered traditionally as the point where consonantal influences on the vowel are less evident (Stevens and House, 1963, *inter alia*). Dynamic analysis consists of quantifying formant slopes from the onset of the vowel to the temporal mid-point via linear and polynomial regression analyses (see also Al-Tamimi, 2007a, 2007b, Submitted).

The data consisted of a list of mono and bi-syllabic words from each dialect, containing the vowels of each dialect in both /d dˤ/ environments. 10 male speakers from each dialect were recruited and they were asked to produce the vowels of their systems in the words at a normal speech rate. Each item was embedded in a carrier sentence adapted to each item, and then was repeated five times and presented randomly to each speaker. Recordings were carried out in a sound attenuated room, via a computer assisted user interface developed specially for this task and digitised directly on the same laptop for the two dialects, with a sampling frequency of 22 KHz, 16 bits, in mono channel. The microphone used was a Sony MS 907 and was placed 30 cm from the speaker`s mouth.

Measurements of the first three formants were extracted automatically using the "Burg" method proposed in Praat (Boersma and Weenink, 2006), using a 12.5 ms Gaussian window, and a 5 ms step. Formant values extracted every 5 ms were then verified manually to prevent automatic error extraction values, and then converted into the psycho-acoustical scale Barks using the following formula: $F_{Bark} = 7 * \sinh^{-1}(\frac{F_{Hertz}}{650})$ (Schroeder et al., 1979), to normalise between speakers. Onset values were determined using the method proposed in Al-Tamimi (2004; Submitted) and were always extracted at 5 ms after the beginning of the first vocalic period. Static analysis corresponded to the formant frequencies extracted at nearly 50% of the vowel duration (at the point where the maximum intensity was detected in a 10 ms window around the mid-point), while dynamic analysis was a regression analysis (linear, 2^{nd} and 3^{rd} polynomial regression analyses) from the extracted onset to the mid-point value, for each formant. From the regression analyses, different coefficients are obtained: the derived starting point of the transition (corresponding to the onset of the formant), the slope steepness value, the mean value and the curvature of the slope (in the 2^{nd} and 3^{rd} polynomials).

Regarding static results, effects of pharyngealisation observed on vowels are consistent with those proposed in the literature: all the vowels produced in the /dˤ/ environment in the two dialects are significantly more open and more back than those produced in the /d/ environment, with respects to the F_1 and F_2 frequencies respectively ($p<0.001$). Regarding F_3, statistical results show that in both dialects F_3 frequencies are significantly lower in the /d/ environment as compared to the /dˤ/ environment ($p<0.03$). When comparing between the two dialects, results show that only F_1 measurements following /d/ differed; vowels were significantly more open in JA ($p<0.001$). No other across-dialect effects on midpoint values were observed.

Regarding dynamic analysis, results show that the values of the slope of the transition are significantly higher for F_2 in JA only: slopes are steeper in the /dˤ/ environment ($p<0.001$). Regarding the starting point of the transition (or the onset), results show that in both JA and MA, F_1 onsets are lower, F_2 onsets are higher and F_3 onsets are lower in the /d/ environment compared to the /dˤ/ environment ($p<0.001$). When comparing the two dialects, results show that the slope of the transition of F_1 is steeper in JA than in MA in the /d/ environment, while it is steeper for F_2 slope in JA in the /dˤ/ environment ($p<0.001$). Regarding the starting point of the transition (or the onset), no differences were observed in the /d/ environment between the two dialects, while significant differences were observed in the /dˤ/ environment: F_1 onset is significantly lower and F_2 and F_3 onsets are significantly higher in JA than in MA.

These results indicate that, compared to the static measurements, the dynamics show more differences between the vowels produced in both consonant environments and between the two dialects with respects to the starting point of the transition. That means the vowels are significantly different at the onset and stay different across the slope of the transition but when arriving at the temporal mid-point lesser differences are observed.

The next step was to assess these differences using a classification method: a cross-validating Discriminant Analysis. The classification rates are presented in the following table (cases in grey indicate lower rates and cases in bold indicate highest rates). These rates indicate that using static analysis did not improve the discrimination of the vowel, either within or across the dialects; instead, using dynamic analysis (linear or polynomial) improves the discrimination. The Discriminant Analysis used the F_2 values at the temporal mid-point as the first parameter to classify between the vowels and between the two languages in the static analysis; while in the three dynamic analyses, the first parameter used was the F_2 starting point in the /dˤ/ environment, indicating that the F_2 onset of the transition is the most robust indicator of the differences between the vowels in /d/ and /dˤ/ environments but also between the two dialects.

	static		linear		2nd polynomial		3rd polynomial	
	/d/	/dˤ/	/d/	/dˤ/	/d/	/dˤ/	/d/	/dˤ/
MA	83.5%	80.4%	88.35	76.0%	87.7%	80.6%	**88.5%**	**81.5%**
JA	69.7%	83.2%	**86.1%**	**89.0%**	83.5%	88.7%	84.1%	84.9%
MA vs. JA	62.5%	49.6%	**63.5%**	77.3%	61.6%	**80.9%**	60.0%	80.4%

These results suggest that some important qualitative differences in the pharyngealised and non-pharyngealised consonants between the two Arabic dialects are available and that the Discriminant Analysis assessed these differences.

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