On Consonant Gemination and Durational Effects in Word-Medial Position in Modern Standard Arabic: A Preliminary Study

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Abstract

This study examines the short/long consonant contrast in word-medial position in Modern Standard Arabic (MSA) which also has contrastive vowel length. Experimental tokens containing Arabic singleton and geminate plosives (/b bː, t tː, k kː, d dː, tˤ tˤː, q qː/) were recorded in a carrier sentence. Results confirm that geminates have significantly longer duration than singletons. The duration difference is smaller following long vowels. Preceding short vowels but not long vowels show some phonetic shortening before geminates. C/V1 ratio significantly increases with long /Cː/ and decreases with long /Vː/, with greater geminate-singleton differences following a short /V/.

Index Terms: gemination, duration ratio, Arabic, Speech Production

1. Introduction

1.1. Background

1.1.1. Stop gemination and acoustic correlates in MSA

Consonant length is fully phonemic in Arabic, which displays a phonological contrast between long (or geminate) and short (or singleton) consonants. This study examines the length contrast in Arabic stop sounds, /b bː, t tː, k kː, d dː, tˤ tˤː, q qː/, as illustrated by the difference between /hadːa/ 'demolished' and /hadaː/ 'showed me the way.'

Consonant gemination has been an area of significant cross-linguistic interest in experimental phonetics ([1–5]), including Arabic. Most phonetic studies to date on gemination in Arabic (e.g., [3]; [6–7]; [8–12]) focus on colloquial varieties, e.g., Lebanese Arabic [13]. Colloquial Arabic can differ significantly in terms of phonetic and phonological form and behaviour according to where it is spoken as well as from Modern Standard Arabic (MSA) which is the standard variety used by educated speakers. There are very few acoustic studies on consonant gemination in MSA [3] and [6-7].

Previous acoustic-phonetic studies on Arabic (including MSA, e.g., [3] and [6-7]) have confirmed that closure duration is the primary acoustic correlate of gemination.

1.1.2. Interactions between vowel length and consonant gemination

Arabic is typologically unusual in that a phonemic length difference occurs not only for consonants but also for vowels, with both types of contrast also intersecting with each other: short and long vowels can appear before either short or long consonants, resulting in a 4-way contrast, e.g., /VCV/ v. /VːCV/ v. /VCːV/ v. /VːCːV/ in word-medial position.

Acoustic studies on gemination have extended beyond the geminate or singleton consonants themselves to examine the interactions between vowel duration on the one hand and adjacent consonant gemination on the other (e.g., [13]; [14]). [15] notes that across languages (e.g., Finnish) geminates are generally associated with a shortening of the preceding vowel, while singletons are usually accompanied by increased duration of the preceding vowel. The languages he refers to involve in almost all cases research results only for phonologically short vowels. However, he cites data for Tamil which like Arabic also has a 4-way contrast to show that vowels in that language, regardless of length category, are shorter before a long consonant - albeit with a bigger effect noted for /VːCː/ vs. /VːC/ (32.5 ms reduction in the former) than for /VCː/ vs. /VC/ (14 ms difference).

In Arabic, vowels preceding geminate consonants are also reported to be subject to some phonetic shortening ([3], [6–7], [10], [13], [16]). However, almost all these studies focus only on the short vowel category before long and short consonants, i.e., /VC/ and /VCː/. [16] for instance, found for Iraqi Arabic a phonetic shortening effect (-16 ms) before geminate consonants (76ms) when compared to the pre-singleton position (92 ms). However, in a rare study to consider the interaction between the consonant and vowel length contrasts, [9] found for Lebanese Arabic that the duration of short vowels is the same before short and long consonants. Instead, there was a small but significant shortening of long vowels before geminates (-17 ms). With respect to C length and duration, there was no effect of vowel length on /Cː/. However, short /C/ was slightly longer (+14 ms) after long /V/. In the only previous study to look at both consonant and vowel length in MSA, [7] reported only a small durational difference between short vowels (-5 ms), and of short /C/ after long v. short /Vː/ (+6 ms). He also noted phonetically shorter /Vː/ (-13 ms) before geminates

One additional useful way to consider gemination is the use of C/V duration ratio values. Previous research on Arabic has focussed on CC/C ratio to establish the relative duration of long to short consonants (e.g., [9]). One element that has generally not been explored previously with respect to word-medial gemination in Arabic (but see [17] on heteromorphemic gemination in Moroccan Arabic) is C/V ratio, which has been used in the analysis of gemination in other languages (e.g. Italian [18, 19], Japanese [20]). The C/V ratio has been regarded as a useful relational measure to normalise for variation in speech and has been found to be a particularly reliable correlate of gemination in languages that show a complementary relationship between the duration of consonants and preceding vowels in the V-C interval, such as Italian [19]. This potential relationship and what it means for MSA remains unexplored.

1.2. Aims

The primary aim of this study is to provide quantitative experimental acoustic findings on the duration of geminate consonants in word-medial positions in MSA. Specifically, it investigates whether geminate consonants are significantly longer than singletons, as reported for other regional Arabic varieties. Additionally, the study explores the effect of the length of the preceding vowel on MSA word-medial gemination, and how consonant length impacts the phonetic duration of short and long vowels. We are particularly interested in whether: (a) there is a concomitant decrease in vowel duration before geminate consonants, and (b) the extent to which the C/V1 ratio increases due to gemination across different vowel length categories.

Unlike previous research specifically on MSA, e.g., [7], who in a study published in Arabic analyzed geminates in word-medial positions with a focus on voicing status, our study focusses instead on the C/V1 ratio to quantify the relationship between geminate consonants and preceding vowels in MSA, offering new insights.

Based on most previous findings, we predict that short vowels will exhibit phonetic shortening before geminate consonants in MSA, as seen in previous studies on Tamil and MSA (e.g., [3], [6-7]) and Arabic dialects (e.g., [10], [13], [16]). However, we expect long vowels to show less or no shortening due to mixed findings for Arabic. Additionally, we predict that geminate consonants (/C:/) will have significantly longer durations than singleton consonants (/C/), consistent with prior findings on MSA [6-7] and other Arabic varieties (e.g., [9], [16]). Finally, we anticipate that the C/V ratio will show a noticeable rise with consonant gemination across both short and long vowel categories. Given that this ratio highlights the balance between consonant and vowel durations within the V-C interval, we expect the impact of gemination to be particularly striking when the vowel is categorically short, as the increased consonantal duration will play a more dominant role in this context.

2. Methods

2.1. Participants

Three Arabic native speakers (2 male and 1 female) took part in data collection. Their ages ranged from 21 to 39. All participants were university students or university educated. They were all MSA speakers, born and raised in Saudi Arabia. At the time of recording, all participants were present in Melbourne for academic pursuits. The participants were not reported to have any history of speech or language impairments.

2.2. Materials and procedure

The original experiment included 180 target words, featuring either a medial singleton or geminate consonant across a series of manners of articulation. We only consider stops here. Some words are minimal pairs, while others are near-minimal pairs, with geminate and singleton consonants following a stressed vowel (e.g., /ˈhaba:/ 'escaped' vs. /ˈhab:a/ 'blew').

Specifically, the experiment selected two sub-sets of disyllabic Arabic words, each illustrating distinct phenomena: a) the contrast between singleton vs. geminate consonants and b) contrastive vowel length before singleton vs. geminate consonants. This allowed for the 4-way length distribution, i.e., /VC/ /VC:V/, /V:CV/ /V:C:V/ in Arabic to be tested with a geminate. Below are instances of the two groups.

A diverse set of Arabic words, including 12 different stop phonemes categorized by place and voice voicing (voiceless: /k-k:, t-t:, tˤ-tˤ:, q-q:/ and voiced: /b-b:, d-d:/) in word-medial position, were carefully selected and examined in this study. Each stop was preceded by the short or long low central vowel, i.e. /a/ or /a:/, and followed by /a:/ or the short high back vowel /u/, as detailed in Table 1.

Two pairs of words were included for each target singleton and geminate sound. All target words in the experiment were disyllabic, with stress placement always on the first syllable.

All participants were asked to read MSA sentences with target words containing one of the geminate-singleton pair words, e.g., /ana: aqu:l (the target word) θa:ni:ja/ < ... نأا قاول ناثية> "I say (the target word) again." Geminate diacritics in Arabic were marked in the target words and in the task (e.g., <بّ>) to avoid potential confusion.

The participants were presented with a Microsoft PowerPoint (PPT) presentation, with each slide containing sentences (including target words – geminate and singleton). The sentence presentation order was randomized. Each sentence was read 5 times. The total number of tokens, after a small number were excluded as errors, utilized in the study for the three speakers amounted to 1075 tokens.

The data were recorded in the Horwood Recording Studio at the University of Melbourne using a Charter Oak E700 dual diaphragm solid state condenser microphone and a Focusrite Scarlett 18i20 gen3 recording interface. The recordings were made at a sampling rate of 44.1 kHz and a quantization rate of 16 bits.

Table 1. *Sample Experimental Word List for Stop Sounds.*

	Ph	Sing CVCV:	Gem CVC:V	Sing CV:CV	Gem CV:C:un
Voiceless Stops	/t/	/mata:/ 'when'	/mat:a/ 'Related by kinship'	/ma:ta/ 'died'	/ma:t:un/ 'formed a bond with someone'
	/k/	/ʃaka:/ 'complained'	/ʃak:a/ 'doubted'	/ʃa:ka/ 'complained'	/ʃa:k:un/ 'doubting'
	/q/	/saqa:/ 'irrigated/ to water'	/ʃaq:a/ 'caused to split/tear'	/sa:qa/ 'narrated (the story)'	/ʕa:q:un/ 'a disobedient child/boy'
	/tˤ/	/χatˤa:/ 'walked'	/χatˤ:a/ 'drew/sketched'	/χa:tˤa/ 'sewed'	/χa:tˤ:un/ 'drawer'
Voiced Stops	/b/	/ħaba:/ 'crawled'	/hab:a/ '(The wind) blew'	/ʃa:ba/ 'Grayed/aged'	/ħa:b:un/ 'a loving person'
	/d/	/hada:/ 'showed me the way'	/had:a/ 'demolished'	/sˤa:da/ 'hunted'	/ha:d:un/ 'destroying'

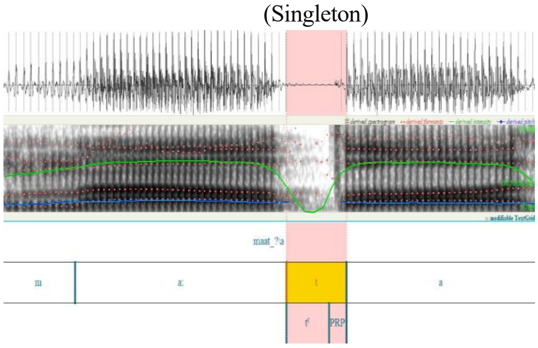
2.3. Acoustic analysis

In the analysis for this study, force-aligned annotations of the recordings were initially conducted using WebMAUS [21] to automatically segment and align the speech data, followed by careful manual adjustments to refine the boundaries of consonant (C) and preceding vowel (V1) segments in PRAAT [22]. An additional tier 'Phonetic' was added to annotate closure and release characteristics of voiceless and voiced stops. Voiceless stops, shown in Figure (1) (a and b), were annotated as follows. The closure phase was identified from the point where the F1 and F2 pattern of the preceding vowel ended and continued until the release of the stop including the stop burst and any aspiration, referred to here as the post-release phase (PRP). The PRP was specifically defined as the time from the release of the stop to the onset of the first formant of the subsequent vowel. For the purposes of this study, whole consonant duration is considered (closure + PRP).

Voiced stops were analyzed with a method similar to voiceless stops to determine the onset of closure and the consonant itself. Unlike voiceless stops, however, voiced stops usually showed a sharp decrease in F1 and F2 energy with low energy voicing throughout the closure phase i.e., a voice bar. The offset of the consonant was identified by a sharp increase in amplitude and energy in F2 and higher frequencies after the release phase.

Consonant duration was measured by calculating the interval between the onset of closure and the onset of the following vowel. V1 duration was measured by calculating interval between the onset and offset of F1 and F2 energy associated with the vowel as indicated in Figure 1a.

(a) Voiceless Stops: Utterance-Medial Position (Singleton)



(b) Voiceless Stops: Utterance-Medial Position (Geminate)

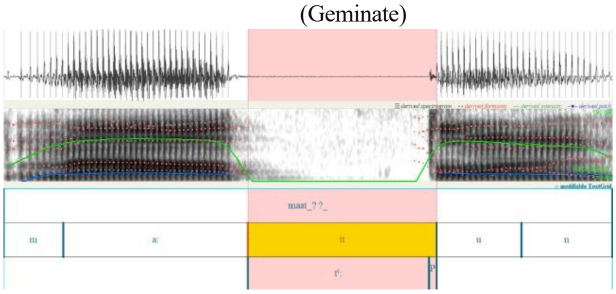


Figure 1: *Examples of two annotated utterance-medial target words produced by an Arabic male speaker, indicating overall C interval plus (1) closure phase for singletons (a) and geminates (b), (2) post-release phase ([PRP]), and (3) preceding vowel intervals*

2.4. Statistical analysis

Data extraction was performed in R [23] using the 'emuR' package that is part of the emu-SDMS software suite [24]. Specifically, duration values were extracted for medial voiced and voiceless stops and the preceding vowel (V1) for all experimental tokens. In this study only overall C duration (closure + PRP interval) was measured. Three separate Linear Mixed-effects Models (LMMs) implemented via the 'lmerTest' package in R [25], examined the effects and interactions of C gemination and V1 phonological length on three key phonetic parameters: C duration, V1 duration, and the ratio of C duration to V1 duration (C/V1 ratio) for all speakers. These models incorporated fixed effects for gemination (singleton vs. geminate) and V1 length (short vs. long). Random intercepts and slopes were included for *Speaker* and *Word* and random slopes for gemination by *Speaker*. Model simplification was also employed using 'step.' Post-hoc analyses were conducted using 'emmeans' to further explore significant interactions among the fixed factors.

3. Results

3.1. C duration

Table 2 and Figure 2 report mean C duration depending on whether C is a singleton or geminate and whether the preceding vowel (V1) is long or short. There is a highly significant main effect of gemination ($F(1,8.97) = 825.304$, $p < .0001$). All three speakers produce significantly longer geminate stops compared to singleton stops. There is also a significant interaction between C and V1 length categories ($F(1,68.61) = 7.397$, $p < .01$). Post-hoc tests revealed a somewhat reduced geminate-singleton C duration difference following a long vowel ($\beta = 142$ ms, $p < .001$) as compared to a short vowel ($\beta = 165$ ms, $p < .001$).

Table 2. *Mean C duration (ms), standard deviation (SD), and token counts (N) by V1 and C lengths with speakers pooled.*

V1 length	C length	Mean C dur (ms)	SD	N
long	gem	262	41	269
long	sing	121	22	269
short	gem	279	30	270
short	sing	115	23	267

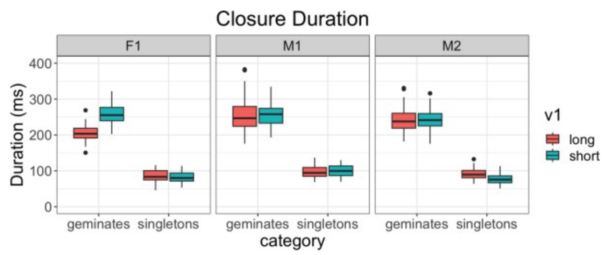


Figure 2: *Consonant duration (ms) plotted by Consonant length category and preceding vowel length category for the three speakers.*

3.2. V1 duration

Table 3 and Figure 3 present the duration of V1 (long or short) preceding either geminates or singletons. The overall effect of C length was not found to be significant ($F(1,68.33) = 1.07$, $p = 0.3167$), indicating that V1 duration does not vary with gemination. Conversely, there is a highly significant main effect of V1 length ($F(1,2.22) = 272.352$, $p < .01$), with phonologically long vowels always longer on average than phonologically short vowels. There is also a significant interaction between gemination and V1 length categories ($F(1,68.33) = 10.613$, $p < .01$). Post-hoc tests reveal that V1 is only ~10 ms shorter preceding geminates than singletons ($\beta = -11$ ms, $p < .01$) when it is phonologically short, while there is no statistically significant difference when it is phonologically long.

Table 3. *Mean V1 duration (ms), standard deviation (SD), and token counts (N) by V1 and C lengths with speakers pooled.*

V1 length	C length	Mean V1 dur (ms)	SD	N
long	gem	243	36	269
long	sing	237	33	269
short	gem	77	20	270
short	sing	87	18	267

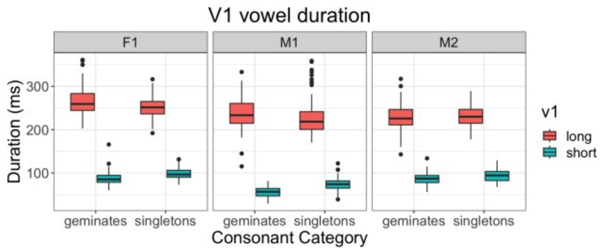


Figure 3: *Vowel duration (ms) plotted according to phonological vowel length and following consonant length category for the three speakers.*

3.3. C/V1 ratio

Table 4 and Figure 4 illustrate variation in the C/V1 ratio according to C length and V1 length. There is a significant main effect of C length ($F(1,2.5) = 39.025$, $p < .05$), with higher C/V1 ratio for geminates than singletons across V1 length types. There is also a significant main effect of V1 length ($F(1,2.14) = 18.15$, $p < .05$), with increased C/V1 ratio for short relative to long V1, regardless of C length. The interaction between consonant and vowel length is highly significant ($F(1,68.53) = 122.647$, $p < .0001$), suggesting that the impact of consonant length on the ratio varies considerably with vowel length. A post-hoc analysis showed a reduced difference in the C/V1 ratio between long and short consonants when the preceding vowel was long ($\beta = 0.59$) compared to when it was short ($\beta = 2.54$).

Table 4: *Mean C/V1 ratio, standard deviation (SD), and token counts (N) by V1 and C lengths with speakers pooled.*

V1 length	C length	Mean C/V1 ratio	SD	N
long	gem	1.11	0.27	269
long	sing	0.52	0.13	269
short	gem	4.00	1.51	270
short	sing	1.2	0.61	267

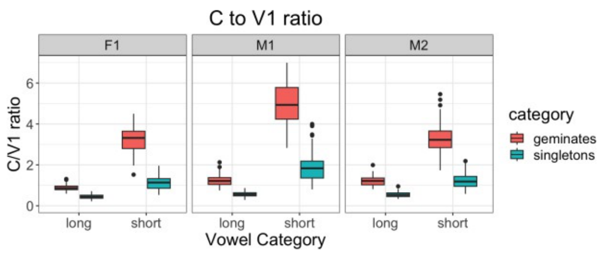


Figure 4: *C/V1 plotted according to phonological vowel length and following consonant length category for the three speakers.*

4. Discussion and Conclusion

In the first instance, this study aimed to determine whether the duration of geminate consonants was longer than that of singletons in medial word positions in MSA. Furthermore, the study investigated (a) whether the phonetic duration of the preceding vowel also co-varied with consonant length for both long and short vowels and (b) whether the C/V1 ratio can be identified as a useful acoustic measure of gemination in MSA. The results have shown that geminates have longer durations than singletons for all speakers, consistent with previous research on different varieties of Arabic (including MSA as well as on other languages, confirming closure duration as the primary acoustic correlate for gemination).

Another point to note is that although this study does not find a significant overall effect of C gemination on the duration of the preceding vowel (V1), in the specific case of phonologically short V1, there is a small but significant shortening effect (~10 ms) preceding geminates. This is in line with cross-linguistic tendencies of pre-geminate vowel shortening [15] which have also previously been reported for Arabic short vowels (e.g. [16]), although not consistently (cf. §1.1.2). However, this pre-geminate shortening effect is not observed for long vowels in this study, in contrast with Lebanese Arabic [9] whereby long but not short V1 shortens before geminates. Similarly, it does not fully align with previous results for MSA [7] which found a bigger phonetic effect on long vowels before geminates.

Furthermore, this study finds that the C/V1 ratio is significantly affected by both C and V1 lengths in MSA. However, a markedly greater geminate-singleton difference is observed following short vowels as compared to long vowels. This is unsurprising as it merely suggests that the effect of C gemination is more visible on C duration where the relative contribution of preceding V1 duration in the V1-C interval is smaller due to its categorically short duration. This differs from Italian whereby the durations of V1 and C are negatively correlated (i.e., the duration of V1 decreases linearly with longer C duration as well as categorically with C length) and the C/V1 ratio provides a measure of this relationship [18]. However, from a normalization perspective, as found for other languages, the C/V ratio may serve as a more stable correlate of gemination than absolute duration across speaking rates in MSA as well as other Arabic varieties, although this needs to be tested in future investigations specifically considering variation in speaking rate.

Overall, the findings indicate that duration patterns play a key role in differentiating between geminate and singleton consonants in MSA. This is anticipated in a language that differentiates phonemic consonant (and vowel) lengths, highlighting the significance of timing in length distinctions.

However, it is important to acknowledge the limitations of this analysis, which was based on data from three speakers and focused on a limited dataset. Future research will broaden the scope to include factors like word-medial and word-final positions, different manners of articulation, phonological voicing, and the impact of both preceding and following vowels of the target words. Including a larger sample of speakers will also help validate the results across different manners of articulation and voicing statuses.

5. References

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