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Ghada Khattab\* and Jalal Al-Tamimi

# Geminate timing in Lebanese Arabic: the relationship between phonetic timing and phonological structure

**Abstract:** This study investigates medial gemination patterns in Lebanese Arabic (LA). It offers an account of the duration patterns of quantity distinction for vowels and consonants in LA by using the most comprehensive dataset for this variety, and for Arabic in general, so far in terms of the number of speakers (20), the consonant types examined (24), the inspection of vowels preceding and following the consonant in durational analyses, and the inclusion of male and female speakers. The main aim is to show correspondence between phonetic timing in LA and phonological accounts of syllabic structure that are based on mora weight (Hayes 1989; Broselow 1995; McCarthy and Prince 1995). The study extends predictions of mora-sharing in disyllables with medial clusters that are preceded by a long vowel (e.g., /'maal.ha/ 'salty-FEM-SG') to comparable syllables with a medial geminate (e.g., /'maal.la/ 'bored-FEM-SG'), which have not been investigated in Arabic before. It shows that vowel shortening preceding medial geminates affects phonologically long but not short vowels, downplaying the commonly referred to closed-syllable shortening effect as the main reason for this phenomenon (Maddieson 1997). Instead, an account based on the interface between phonetic and phonological effects on compensatory vowel shortening offers better predictions.

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## 1 Phonetic manifestations of gemination

Geminates are known as long or doubled consonants, which contrast with short or singleton consonants, e.g., Lebanese Arabic (LA) /'katab/ 'he wrote' vs. /'kattab/<sup>1</sup>

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<sup>1</sup> The double consonant notation is used in this article throughout to represent the geminate sound at the prosodic (C<sub>G</sub>C<sub>G</sub> or CC) or phonemic/melodic (/tt/) level, not just the phonetic level. The notation tends to vary considerably across studies, with C, C:, CG/C<sub>G</sub>, or G being used to denote a geminate consonant.

'he made someone write'. From a phonetic point of view, gemination is mainly manifested as lengthening of the consonant, and consonant duration has been shown to be the major cue for gemination in many languages (e.g., Ghalib 1984; Lahiri and Hankamer 1988; Local and Simpson 1999; Arvaniti 1999, 2001; Ham 2001; Hassan 2002, 2003; Ladd and Scobbie 2003; Blevins 2004; Payne 2005; Ridouane 2007). The magnitude of the difference between singleton and geminate consonants varies within and across languages. Within languages, manner of articulation of the consonant has been shown to influence the geminate-to-singleton ratio and, subsequently, how important the duration cue is for the contrast. For instance, sonorants show more distinct geminate-to-singleton ratios while sibilants have less distinct ratios, partly due to singleton sibilant consonants like /s/ and /ʃ/ being intrinsically long (Tserdanelis and Arvaniti 2001; Blevins 2004; Aoyama and Reid 2006). Place of articulation has also been shown to influence consonant duration and the appearance of geminates, with bilabial and alveolar geminates being generally longer than velar ones, and alveolars being the most common type of geminates (Thurgood 1993; Local and Simpson 1999). With respect to voicing, voiced sonorants are the easiest to maintain and make 'good' geminates, while voiced obstruents are the most difficult to geminate due to the difficulty in maintaining voicing during the closure. As a consequence, they are subject to devoicing in many languages (Ohala 1983; Blevins 2004).

Languages seem to vary considerably with respect to the durational difference between the singleton and geminate consonants (Ladefoged and Maddieson 1996: 92). Berber and Finnish are reported to have a 3 to 1 ratio (e.g., Aoyama 2002; Ridouane 2007), compared with around 2 to 1 (or lower) in Japanese, Italian, and Turkish (e.g., Lahiri and Hamkamer 1988; Aoyama 2002; Payne 2005). Preceding vowel duration has also been found to interact with consonant length, but there are conflicting results in the literature regarding whether or not vowels shorten before geminate consonants (e.g., Homma 1981; Lahiri and Hankamer 1988; Cohn et al. 1999; Esposito and Di Benedetto 1999; Ham 2001; Hassan 2003, to name a few). This relates to various universal and language-specific phonetic and phonological phenomena which will be discussed in more detail in Section 3. As for the vowel following the coda consonant ( $V_2$ ), relatively little research has been carried out on its duration and on whether its length is influenced by whether the preceding consonant and first vowel ( $V_1$ ) are short or long. In Finnish (Aoyama 2001), Japanese (Idemaru and Guion 2008), and Malayalam (Local and Simpson 1988), the  $V_2$  has been found to be shorter in geminate than in singleton contexts, and shorter than  $V_1$  in the geminate context. Local and Simpson (1988) explain these results by referring to the rhythmic properties of syllables in Malayalam. Nakai et al. (2009) further find that  $V_2$  is shorter in the context

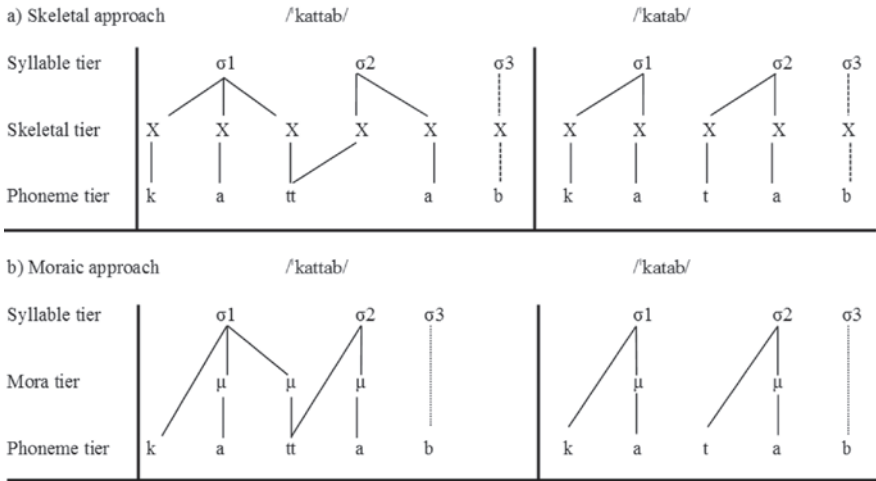
of a long rather than a short  $V_1$  in Finnish. In none of these studies, however, has  $V_2$  acted as a major cue for distinguishing between the singleton-geminate contrast, which may be why more emphasis has been placed on  $V_1$  and consonant length.

Non-temporal manifestations of gemination have also been reported in many studies. These include spectral characteristics of the preceding and/or following vowels (e.g., more peripheral and/or closer preceding vowels), creaky and/or tense phonation, clearer consonantal resonance in sonorants, and sharper/firmer and flatter closures in stops (e.g., Hankamer et al. 1988; Local and Simpson 1988, 1999; Abramson 1991; Esposito and Di Benedetto 1999; Arvaniti and Tserdanelis 2000; Tserdanelis and Arvaniti 2001; Payne 2005, 2006; Ridouane 2007; Idemaru and Guion 2008). These manifestations suggest a tense/lax distinction that is thought to enhance the perceptual distance between singletons and geminates. In some languages, including Malayalam, the phonetic effects of the singleton-geminate contrast are exhibited over long domains, influencing preceding and following syllables (Local and Simpson 1999).

While consonant gemination in LA is very frequent and plays an important role in the grammar of the language (see Section 4), little is known about the phonetic realisation of singleton and geminate targets in this dialect or about the role played by the preceding vowel. The same is true regarding phonemic vowel length (cf. Khattab 2007; Khattab and Al-Tamimi 2008).

## 2 Phonological representation of medial geminates

While early phonological representations (e.g., Chomsky and Halle 1968) depicted geminates as single consonants with a [+long] distinctive feature, the predominance of non-linear phonology over the last 30 years has shown that geminates can occupy more than one timing unit at the prosodic level or have more than one syllable affiliation (see Davis [2011] for a review of the phonological representation of geminates). Two main approaches to the representation of geminates within non-linear models of phonology have dominated the literature for some time. Their analyses have a significant bearing on whether or not geminates are linked to two slots on the prosodic tier, and whether or not they are considered to have inherent weight; this issue is relevant for languages with constraints on syllable weight (e.g., the occurrence of light and heavy/superheavy syllables), stress, and minimum word size.



**Fig. 1:** Representation of an intervocalic geminate using (a) skeletal and (b) moraic analyses. Note that final consonants in Lebanese Arabic count as extra-metrical for stress purposes (McCarthy and Prince 1990), hence the /b/ links to a third syllable.

In skeletal analyses of the syllable, geminates are single long phonemes which are linked to two slots on a prosodic tier; these are normally labelled using X or C/V slots (e.g., McCarthy 1979; Leben 1980; Tranel 1991). Within this analysis a geminate consonant has two timing slots and the singleton just one (Figure 1a), and consonants occupy a timing slot regardless of whether they are in onset or coda position. Phonological length is induced from the timing tier; however, this does not specify weight, which is a major distinction between skeletal and moraic approaches. Variations on this representation include a two-root node representation which can arguably explain the occurrence of a geminate split, e.g., by epenthesis (McCarthy 1988; Selkirk 1990; Ringen and Vago 2011) or of initial geminates (Hume et al. 1997).

In Moraic Theory (Hayes 1986, 1989; McCarthy and Prince 1995; Davis 1999), geminates are attached to a moraic node and a syllabic node and there is a connection between weight and length on the one hand, and weight and syllable position on the other. For instance, short vowels have one mora, long vowels have two moras, singleton consonants are weightless (but may acquire weight in coda position), and geminates have one mora. Therefore, while geminate consonants are weight-bearing, onset consonants do not contribute to syllable weight and the weight of coda consonants varies from one language to the other (Hyman 1985; Hayes 1989; Broselow et al. 1997). In languages where a ‘Weight by Position’ rule applies (Hayes 1989: 259), coda (but not onset) consonants are assigned a mora.

The consequence of these rules for intervocalic geminates in many languages is that they are doubly linked to the rhyme of the first syllable where they act as a weight-bearing coda, and to the onset of the second syllable where they act as a weightless onset (Figure 1b).

Of main interest to this study is the debate around whether or not geminates are weight bearing. A weight-bearing account would suggest that syllables that are closed with geminates are always heavy. This account works well for LA (see Section 4 on gemination in LA below), a quantity-sensitive language in which syllable weight governs stress patterns and minimal word structure. However, Moraic Theory poses problems for languages like Leti, Malayalam, Ngalagan, and Selkup, where syllables closed with a geminate are considered light (Tranel 1991; Hume et al. 1997; Baker 2008; Ringen and Vago 2011). This has led Hume et al. (1997) to suggest that geminates are inherently non-moraic, while Broselow et al. (1997) suggests a solution using mora-sharing with the preceding vowel.

There is also disagreement as to whether or not Moraic Theory makes predictions about surface timing. On the one hand, moras can be considered abstract units which form the lowest level of the prosodic structure (Hayes 1989: 285) and serve as the link between prosodic and segmental information. On the other hand, it should be possible to make phonetic predictions of length based on moraic timing if one were to argue for a closer relationship between phonological structure and phonetic timing (Cohn 2003). Broselow et al. (1997) draw a straightforward relation between moras and duration. In their analysis of word-internal heavy syllables in Hindi, Malayalam, and Levantine Arabic, they suggest that whether or not consonants contribute to coda weight and whether languages allow trimoraic syllables is language-specific; as a result of that, the durational patterns of vowels and consonants portray different moraic representations for word-internal CVC and CVVC syllables in each language. For instance, Hindi allows superheavy syllables, and coda consonants are always weight bearing; this leads vowels in internal CVVC syllables to have the same duration as in CVV syllables, as in (1), and coda consonants in internal CVC syllables to have the same duration as in CVVC (2) (Broselow et al. 1997: 53–55).

(1) /kaaʔ.na/ ‘to cut’ vs. /kaa.ʔaa/ ‘cut-PERF’

(2) /kaʔ.naa/ ‘to be cut’ vs. /kaaʔ.na/ ‘to cut’

In Malayalam, on the other hand, coda consonants are always weightless and share a mora with the preceding vowel, leading (long and short) vowels to be shorter in closed syllables (3), while consonants maintain the same length in CVC

and CVVC since mora sharing happens in both (4) (Broselow et al. 1997: 54–56). These results can shed light on the debate around temporal compensation in closed syllables, which is discussed in the next section before we return to Broselow et al.’s prediction for moraic representations of word-internal codas following short and long vowels in Levantine Arabic in Section 4.

- (3) /pa.t̪i/ ‘husband’ vs. /pat.ram/ ‘leaf’  
 /paa.t̪i/ ‘half’ vs. /paat.ram/ ‘vessel’  
 (4) /pat.ram/ ‘leaf’ vs. /paat.ram/ ‘vessel’

### 3 The potential contribution of a moraic approach to the discussion around temporal compensation in closed syllables

Arguments for a moraic approach to syllables have often revolved around compensatory lengthening (e.g., Hayes 1989; Maddieson 1993; Broselow 1995), whereby syllables with heavy codas which lose one coda over time undergo vowel lengthening of the preceding vowel but not if the same consonant is in onset (and therefore weightless) position. As an illustration of this, Hayes (1989: 260–261) refers to the diachronic loss of /s/ from Latin before anterior sonorants, which triggered lengthening of the preceding vowel when in coda position, but no change in initial position, e.g., \*kasnus > ka:nus ‘gray’, but \*snurus > nurus ‘daughter-in-law’. The same argument works for closed-syllable shortening, a phenomenon which is often assumed to be universal on phonetic grounds, but which has shown conflicting language-specific patterns which suggest phonological effects that become learned behaviour. There is an assumed universal tendency for vowels in open syllables to be phonetically longer than in closed syllables (Maddieson 1997). Several articulatory, acoustic, and perceptual explanations have been provided for this observation. For instance, there is a belief that the rhythmic structure of words needs to be sustained by balancing the duration of adjacent phonetic segments so that words with equal numbers of syllables do not change in utterance length (Lehiste 1971; Maddieson 1997; Esposito and Di Benedetto 1999). In this case a coda consonant may draw on duration from the preceding vowel to preserve the phasing between the onsets of the vowels surrounding the consonant (Maddieson 1997: 625) and vice versa (i.e., the consonant may shorten if the preceding vowel is long).

In the case of disyllables with medial singleton and geminate consonants, the assumption is that the preceding vowel is phonetically shorter in the gemi-

nate than in the singleton context since the geminate consonant is ambisyllabic.<sup>2</sup> Arguments include the fact that more energy is required for the production of a geminate consonant due to the need to move and hold the constriction for longer duration (Catford 1977: 298) or due to the increased muscular tension and higher oral pressure (Ridouane 2007). This is thought to take away from the total duration of the syllable containing a geminate as opposed to its single counterpart (Belasco 1953: 1016); however, this view would suggest that syllables with geminates are comparable in length to those with singletons, which may not necessarily be the case. It is important to look at the rhythmic structure of the language in order to better understand how the phasing between vowels and consonants works within and across syllables. Local and Simpson (1988: 37–40), for instance, suggest that the rhythmic quantities for disyllables in Malayalam geminate forms are equal, whereas in the singleton form they are short-long. This allows the vowel preceding a geminate to maintain the same length as the one preceding a singleton form given the different rhythmic structure.

Another issue relates to the role of perceptual distinction in a phonological contrast: in the case of medial closed syllables when the coda consonant is a geminate, preceding vowel shortening is thought to enhance the perceptual contrast between the geminate and singleton consonants. This has been supported by evidence of vowel and/or consonant shortening in various languages (e.g., F. Al-Tamimi [2004] on Jordanian Arabic; Cohn et al. [1999] on Buginese, Madurese, and Toba Batak; Esposito and Di Benedetto [1999] on Italian; Ham [2001] on Madurese; Hassan [2002] on Swedish; Ridouane [2007] on Tashlhit Berber; Poddesva [2000] on Buginese and Selayarese). However, studies that have found no or inconsistent evidence of temporal compensation in preceding vowels include Hassan (2003) and Ghalib (1984) on Iraqi Arabic, Hansen (2003) on Persian, Homma (1981) on Japanese, Lahiri and Hankamer (1988) on Bengali and Turkish, McKay (1980) on Rembarrnga, and Tserdanelis and Arvaniti (2001) on Cypriot Greek. In languages like Persian (Hansen 2003), Finnish (Suomi and Ylitalo 2004), and Japanese (Idemaru and Guion 2008; Kingston et al. 2009), the preceding vowel has actually been reported to be longer when preceding geminates than when preceding singletons. Due to the conflicting results regarding the role of preceding vowel length, the major cue for singleton and geminate distinction remains the duration of the consonant itself (Lahiri and Hankamer 1988; Esposito and Di Benedetto 1999; Arvaniti and Tserdanelis 2000; Ham 2001; Ladd and

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<sup>2</sup> Note that the phonetic shortening described here does not result in a loss of contrast between phonologically long and short vowels in a given language but is rather allophonic.

Scobbie 2004; Idemaru and Guion 2008; Ridouane 2010) or the ratio of the consonant to the preceding vowel (Pind 1999; Hansen 2004).

Conflicting results from the above studies suggest that the phonetic motivations for temporal compensation are by no means inevitable and may actually be under the control of the speaker, depending on the language-specific timing patterns that they have acquired and that become encoded in the phonology. These patterns may depend on how a language deals with the relationship between syllable structure, syllable position, and weight. The interesting result about longer preceding vowels before geminates in Persian, Finnish, and Japanese reported above brings up two issues: these are languages where vowel quantity is contrastive as well, which necessitates a closer look at how phonologically short and long vowels behave when preceding singleton and geminate consonants. Second, the results from Japanese refocus our minds on moraic timing again, given that the mora plays a major role in Japanese timing. In languages where vowels and geminate consonants each occupy their own mora, there is no motivation for vowel shortening unless there is a language-specific constraint on superheavy syllables (McCarthy and Prince 1990), which would predict shortening in syllables with phonologically long vowels (in order to avoid trimoraic syllables), but not in syllables with short vowels. This issue will be investigated in the current study (Section 4).

## 4 Gemination in LA

Quantity distinctions between both consonants and vowels play a major role in Arabic phonology and morphology (McCarthy 1979, 1981, 1986; McCarthy and Prince 1990, 1995). In LA, all 24 consonants can be geminated. Vowel length is also contrastive, and both long and short vowels occur before geminate consonants (Nasr 1960, 1966; Ham 2001). Word-medial consonants can therefore occur in the following trochaic contexts:

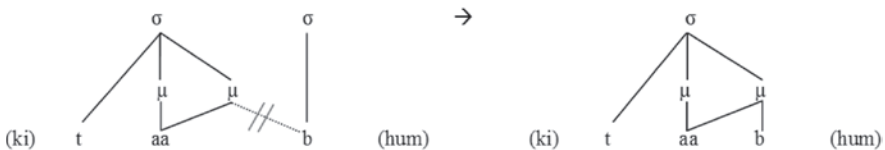
'CV.CVC /'ħa.kam/ 'referee'      'CVV.CVC /'ħaa.kam/ 'he tried'  
'CVC<sub>G</sub>.C<sub>G</sub>VC /'ħak.kam/ 'he treated'      'CVVC<sub>G</sub>.C<sub>G</sub>V /'ħaak.ka/ 'scratched-FEM-SG'

True geminates in LA can also occur in final position (e.g., /ʕam/ 'to be' vs. /ʕamm/ 'uncle'; /ʕaam/ 'he floated' vs. /ʕaamm/ 'public') and in initial position, where gemination is derived as a result of vowel syncope and assimilation between the definite article /al/ and following coronal sounds (Standard Arabic /al/ + /suuq/ 'the market' > /assuuq/ > [issuuʔ] or [ssuuʔ] in LA). The minimal word structure and stress patterns in LA provide evidence for a weight distinction

that is driven by moraic timing (Broselow et al. 1997; Ham 2001; Watson 2007; Davis and Ragheb to appear): onset consonants are weightless while codas acquire a mora due to the Weight by Position rule (Hayes 1989: 258). Hence CV syllables in LA are light, CVV and CVC are heavy, while CVVC and CVCC are super-heavy. Words are minimally bimoraic, as evidenced by the paucity of monosyllabic words with underlying CV. Words are also optimally bimoraic following the Syllable Binariness rule (Broselow et al. 1997: 65), which has led to a debate around the status of superheavy syllables, which are potentially trimoraic. In word-final position, one solution is for final consonants to be considered extra-metrical (McCarthy and Prince 1990), which works well for stress assignment purposes in LA: stress falls on the rightmost syllables that are phonologically heavy, or else on the penultimate syllable (e.g., /'ma.la.k/ 'king', /'mad.ra.sa/ 'school', and /'maa.la.k/ 'your money', but /ma.'laa.k/ 'angel' and /mal.'laa.k/ 'owner').

In word-internal position (e.g. /ki.taab.hum/ 'their book'), mora sharing with the preceding vowel is predicted in order to preserve the bimoraic structure of the syllable (Figure 2), following the Adjunction-to-Mora principle (Broselow 1992: 14–15). This refers to cases where a following suffix (like -hum in Figure 2) prevents /b/ from occupying an extrametrical syllable, requiring an affiliation with the preceding syllable in some dialects (as exemplified in Figure 2) or epenthesis in others (McCarthy and Prince 1990).

Broselow et al. (1997) provide phonetic evidence for this from Levantine Arabic (the variety spoken in the Levant, the area covering Lebanon, Syria, Jordan, and Palestine). In this variety mora sharing in superheavy syllables is reflected in the longer duration of vowels in internal CVV than CVVC syllables, see (5), but no difference in V duration between CV and CVC (6). Similarly, coda C is longer in internal CVC than in CVVC syllables (7) (Broselow et al. 1997: 59–60). Long vowels in CVV syllables were on average 16% longer than long vowels in CVVC syllables, while coda consonants in CVC syllables were on average 31% longer than coda consonants in CVVC syllables. This suggests that the phonological relationship



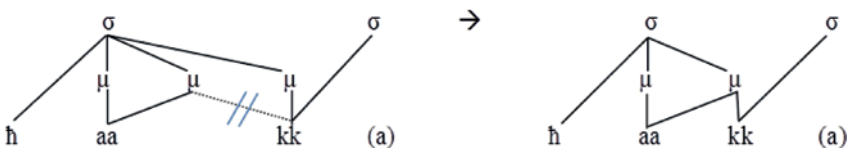
**Fig. 2:** Adjunction-to-Mora representation of CVVC syllable in /kitaab-hum/ [kitaabhum] 'their book', showing the consonant /b/ sharing the rightmost mora of the long vowel /aa/ (modified from Broselow 1992: 14–15).

between consonant clusters and long vowels is clearly reflected in the phonetic implementation.

- (5) /ki.taa.bi/ ‘my book’ vs. kitaab.hum/ ‘their book’  
 (6) /ʕi.na.bi/ ‘my grapes’ vs. /ʕi.nab.hum/ ‘their grapes’  
 (7) /ʕi.nab.hum/ ‘their grape’ vs. /ki.taab.hum/ ‘their book’

Broselow et al. (1997) argue that the stress patterns in LA provide no motivation for a three-way distinction in syllable weight, suggesting that superheavy syllables eventually surface as heavy. However, while the coda consonants discussed in (7) are singleton consonants in a cluster sequence, the present study raises the issue of whether this analysis extends to internal  $VVC_G$  syllables that are the left leg of a geminate (e.g. /ʕaak.ka/ ‘scratched-FEM-SG’). This requires a different representation from that of medial clusters in Figure 2, as the geminate is heterosyllabic and is inherently moraic, rather than acquiring weight by position like singleton consonants. This leaves open the question of how the Adjunction-to-Mora principle would apply. If the avoidance of trimoraic syllables in LA is crucial, then one might expect a similar outcome to that found for clusters, with mora sharing between the long vowel and the geminate consonant (Figure 3).

In terms of phonetic predictions, VV in  $CVVC_G C_G V$  should be shorter than in  $CVVCVC$  /'maa.lak/ ‘your money’ (8), but short vowels should not be affected by this (9). Kiparsky (2003) and Watson (2007) suggest that this indeed is the case, but quantitative evidence is only available for the outcome in short vowel contexts (Ham 2001). In his study of Levantine Arabic,<sup>3</sup> Ham (2001: 134) highlights the lack of vowel shortening in short vowel contexts followed by medial geminates, but did not elicit  $CVVC_G C_G V$  data in order to test the predictions in long



**Fig. 3:** Application of the Adjunction-to-Mora principle to medial  $CVVC_G$  syllables, with an example from /ʕaak.ka/, which would reduce the syllable from trimoraic to bimoraic.

<sup>3</sup> Two of the participants were from Jordan and the third from the West Bank, but the words the participants read were embedded in carrier sentences that were read in a formal register (/qu:l bæ:bi mara θanja/ ‘say my door again’).

vowel contexts. What remains to be investigated is whether mora sharing between long vowels and medial geminate consonants triggers shortening in the geminate context as well (10), or whether geminates exhibit different behaviour from clusters. Little is known about whether the geminate consonant itself shortens as well.

(8) /<sup>l</sup>maal.la/ ‘bored-FEM-SG’ vs. /<sup>l</sup>maa.lak/ ‘your money’

(9) /<sup>l</sup>ma.lak/ ‘king’ vs. /<sup>l</sup>mal.la.k/ ‘he made someone own’

(10) /<sup>l</sup>mal.la.k/ ‘he made someone own’ vs. /<sup>l</sup>maal.la/ ‘bored-FEM-SG’

## 5 Aims of the present study

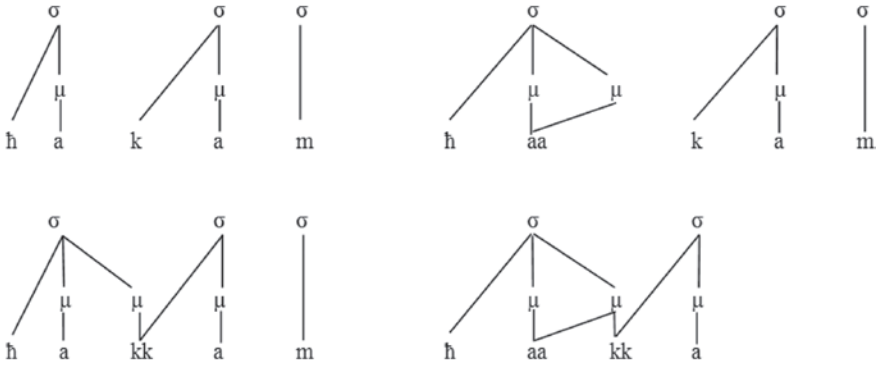
The present study aims to explore the mutual influence between patterns of phonetic timing and theories of representation. As the most comprehensive study of gemination in LA to date, the study looks at singletons and geminates for all consonant types in this variety (therefore covering all possible places, manners of articulation, and voicing states) and at data from 20 speakers, providing an opportunity to examine quantitative and qualitative aspects of gemination. The study seeks to answer the following research questions:

1. What are the temporal manifestations of the singleton-geminate contrast in LA? Here we will look at the singleton-geminate ratio in LA and provide an account of the intrinsic influences on consonant duration, with a focus on manner of articulation of the consonant.
2. How does a mora-sharing account contribute to the understanding of the temporal relationship between medial consonants and preceding long and short vowels in LA?

Figure 4 and Table 1 show the phonological representations of the four syllable structures under examination and the predictions for phonetic timing based on moraic weight. For ease of reference, the four syllable structures will henceforth be referred to using the medial sequence only, without using the <sub>0</sub> subscript for CC:<sup>4</sup>

$$\begin{aligned} {}^l\text{CV}_1.\text{CV}_2\text{C} &= {}^l\text{V}_1.\text{CV}_2 & {}^l\text{CVV}_1.\text{CV}_2\text{C} &= {}^l\text{VV}_1.\text{CV}_2 \\ {}^l\text{CV}_1\text{C}.\text{CV}_2\text{C} &= {}^l\text{V}_1\text{C}.\text{CV}_2 & {}^l\text{CVV}_1\text{C}.\text{CV}_2 &= {}^l\text{VV}_1\text{C}.\text{CV}_2 \end{aligned}$$

<sup>4</sup> This decision was made given that we are not looking at clusters in this study, so there is no need to keep the two separate.



**Fig. 4:** Mora-based representation of medial singleton and geminate consonants preceded by phonologically short and long vowels.

**Table 1:** Predicted syllable weight following a mora-based analysis. Segments that carry weight are underlined.

Lexical item	<sup>l</sup> ħa.kam	<sup>l</sup> ħaa.kam	<sup>l</sup> ħak.kam	<sup>l</sup> ħaak.ka
Gloss	<i>referee-</i> <i>MASC-SG</i>	<i>tried-</i> <i>MASC-SG</i>	<i>treated-</i> <i>MASC-SG</i>	<i>scratched-</i> <i>FEM-SG</i>
Syllable structure	<sup>l</sup> V <sub>1</sub> .CV <sub>2</sub>	<sup>l</sup> VV <sub>1</sub> .CV <sub>2</sub>	<sup>l</sup> V <sub>1</sub> C.CV <sub>2</sub>	<sup>l</sup> VV <sub>1</sub> C.CV <sub>2</sub>
Moraic links in first syllable	1	2	2	3
Moras in first syllable	monomoraic	bimoraic	bimoraic	bimoraic
Syllable binarity effect	no mora sharing	no mora sharing	no mora sharing	mora sharing

The analysis that follows from this account is that geminates are monomoraic and syllabify with the coda of the first syllable and the onset of the second syllable. However, they do not shorten the preceding vowel because they make CV<sub>1</sub>C heavy, not light. Weight is therefore expected to be similar to that of CVV<sub>1</sub>, which is considered heavy and has twice the length of CV<sub>1</sub>. As for target words with medial VV<sub>1</sub>C.CV<sub>2</sub> structure, these are expected to show shortening of both VV<sub>1</sub> and possibly CC due to the bimoraic limit of the syllable and the need for mora sharing in order to avoid a trimoraic syllable. Another possibility is for the consonant to retain its weight while the vowel shortens. While the mora sharing analysis is normally applied to consonant clusters under the Adjunction-to-Mora principle for Eastern Arabic dialects (Broselow 1992: 14–15; Broselow et al. 1997), it may be the case that the medial geminate weight is retained in order to distinguish between medial clusters and geminates in VV<sub>1</sub>C.CV<sub>2</sub> structure, or it could be

that trimoraic syllables are allowed in LA in the case of a medial geminate. This leads to the following predictions:

1.  $V_1$  in  ${}^1V_1C.CV_2$  is comparable in duration to  $V_1$  in  ${}^1V_1.CV_2$
2.  $VV_1$  in  ${}^1VV_1C.CV_2$  is shorter than in  ${}^1VV_1.CV_2$

Vowel duration is therefore expected to show the following pattern:  $VV_1 > VV_1C > V_1 = V_1C$ .

3.  $CC$  in  ${}^1VV_2C.CV_2$  is shorter than in  ${}^1V_2C.CV_2$  or comparable in duration if geminate consonants are not affected by mora sharing in the same way as consonant clusters

Consonant duration is therefore expected to show the following pattern:  $V_1CC \geq VV_1CC$

The main test for the moraic account is therefore in the varying way in which preceding vowel duration interacts with a coda consonant. If the duration is shortened only in phonologically long vowels, then this would constitute strong support for a moraic account of medial gemination. If, on the other hand, the preceding vowel shortens regardless of its phonological length, then this may be due to the more generally assumed phonetic effect of closed syllable shortening (Maddieson 1997).

## 6 Methodology

### 6.1 Speakers and data processing

Twenty subjects (10 males and 10 females) with no reported history of speech or language disorders and aged between 18 and 40 were recruited in Beirut. All subjects were university-educated and were born and raised in Lebanon. At the time of recording, half of them had lived in Beirut for most of their lives, while the other half had studied there for at least 2 years, but no other criteria were used to control for their dialectal background. All subjects were also exposed to English, and in some cases French, due to the multilingual nature of Lebanon.

The subjects were audio-recorded in a quiet room either in an office or in their homes while reading a randomized word list with target short and long vowels and consonants in four trochaic structures. The four word structures are shown and exemplified in Figure 4 and Table 1. The disyllables consisted of minimal or near-minimal sets (more on this below). These included words with all LA consonants and were randomized before presentation. Fillers were also included at the beginning and end of each page in order to minimise effects from intonation at the beginning and end of a reading list. A total of 296 target tokens from each

subject were used for this particular study, to include 24 consonants, 4 syllable structures, 3 examples, and 8 fillers.

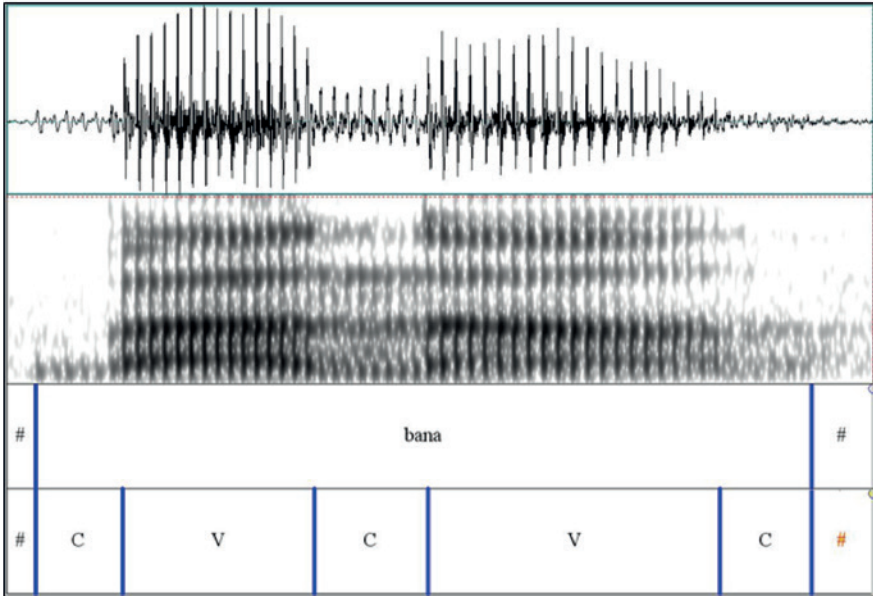
The recordings were made digitally in mono with a 16-bit, 44.1 kHz sampling rate, using an Edirol R9 solid-state recorder and a SONY MS957 Uni-Directional Stereo Electret Condenser microphone. In order to overcome the problem of associating written stimuli with the use of Standard Arabic (vernacular Arabic is normally only spoken), the spelling and diacritics of target words were adapted to the colloquial LA pronunciation, and the whole session including instructions was carried out in colloquial Arabic. Subjects were instructed to produce the written words as if they were speaking them in their own variety in an informal style and normal rate. Initial trials were done and 19 out of our 20 subjects had no problems completing the task in a vernacular style. One subject consistently switched to a standard style and was consequently replaced by another subject. We are confident that the elicited data are representative of the LA variety, but even if there had been an influence from the Standard variety, we are not aware of any major differences in the realisation of gemination between LA and the Standard variety.

Designing near-minimal sets for the four word types was challenging due to the low frequency of occurrence of target words with  $VV_1C.CV_2$  structure. Some of the words with this structure were rejected by the subjects who stated that they used a different word for the same target (e.g., /zih'ʔaane/ instead of /'meelle/, both meaning 'bored-FEM-SG'), which yielded fewer tokens for this context compared with the other three (1 or 2 examples rather than 3 for some subjects). The target vowel before ( $V_1$ ) and after ( $V_2$ ) the medial consonant in each case was /a/ or /aa/, though the long vowels were sometimes raised due to *Imala*, a process that involves raising long /aa/ vowels to [ee] in LA (Nasr 1966), e.g., [ʰheekam] 'he tried' and [ʰheekke] 'scratched-FEM-ADJ'. The following LA consonants were elicited in their singleton and geminate form: /b, t, tʰ, d, dʰ, k, ʔ, f, s, sʰ, z, ʒ, ʒ, x, ɣ, h, h, m, n, l, r, w, j, ʕʕ/, but /j/ was subsequently excluded from the analysis due to insufficient number of tokens from all required syllable structures.

With the exception of the  $^1VV_1C.CV_2$  structure, three tokens per participant for each of the target consonants in each of the syllable types were elicited and used for auditory and acoustic analysis using PRAAT version 5.1.0 (Boersma and Weenink 2009). A small number of tokens were eventually discarded during the analysis phase due to noise or other technical problems. The data were labelled semi-automatically using the package STK (Farinas et al. 2005). This method

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5 /ʕʕ/ is classified as an approximant rather than a fricative due to its common realisation as such in LA; this was confirmed by the acoustic and auditory patterns that were found in this study.



**Fig. 5:** An illustration of data labelling showing the word /bana/ ‘he built’ as produced by one of the male speakers and realized with a breathy offset to the second vowel. Breathy offsets were not considered as part of the vowel but were included in the calculation of word duration.

adds boundaries of C and V intervals based on the computation of  $F_0$  and intensity. Once the labelled data were obtained, a PRAAT script specifically designed by the second author was used to transfer the boundaries into TextGrids. Then a manual inspection of the boundaries was carried out to check for potential errors in the automatic extraction (example in Figure 5). A total of 5,171 word-list tokens were analysed.

The following measurement criteria were adopted, using modified criteria from Turk, Nakai, and Sugahara (2006):

- For  $V_1$  the beginning was determined in accordance with the rise in amplitude from the previous consonant and appearance of formant structure, and the end in accordance with the drop in amplitude and disappearance of or abrupt change in formants.
- The boundaries for medial stops were determined according to the drop in amplitude and disappearance of formant structure in the preceding vowel and start of voicing and formant structure in the following vowel. In the case of stops, the consonant phase itself was typically (but not always) marked by a period of complete or near absence of acoustic energy, followed by the

release burst and a period of delay in voice onset time and/or frication before the start of the following vowel.

- The boundaries for medial fricatives were determined according to the onset and offset of visible and/or audible friction, including any period of silence which sometimes preceded the start of the following vowel.
- Nasals, laterals, and approximants (including the voiced pharyngeal fricative) were mainly identified through the drop in amplitude and beginning/end of transitions in the surrounding vowels, coupled with absence of higher formants for approximants and /ʕ/. Deciding on the exact spot for the beginning and end of transitions was a challenging task, but the semi-automatic procedure that was used enabled the authors to decide on the boundaries based on a combination of changes in  $F_0$ , visual inspection of the spectrogram, and auditory impression.
- Taps and trills were delimited from the drop in amplitude and/or cessation of formants in the preceding vowel (but not formant shadows) to the rise in amplitude indicating the release of tongue contact and start of formants in the following vowel. Where taps and/or trills were realised as approximants, the labelling followed the same procedure as for laterals and approximants.
- For  $V_2$ , the onset coincided with the end of the preceding consonant. The end of  $V_2$  was marked in accordance with any intensity variation observed on the spectrogram and/or the waveform. Where  $V_2$  was in final position and the last part was voiceless and low in amplitude, the end boundary was placed before the start of formant shadows/end of voicing and a hypothetical consonant was labelled to represent the last portion (Figure 5). This was done in order not to include this last portion in the analyses of  $V_2$ , following work by Nakai et al. (2009) which suggests that the voiceless offset does not contribute to the perception of length in this vowel. It was not our intention to analyse the hypothetical consonant or claim its phonological status.

The following durational measurements were made:

- the first target short or long vowel, henceforth  $V(V)_1$
- the medial target singleton or geminate consonant, henceforth  $C(C)^6$
- the second target short vowel, henceforth  $V_2$
- the whole word

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<sup>6</sup> Within the medial  $C(C)$ , many other durational measures were taken but these are discussed elsewhere (Al-Tamimi and Khattab 2011, under review). For instance, the durations of voiced and voiceless periods were computed. For stops, the following additional durational measurements were made: closure duration, voice onset time (VOT), release burst, aspiration.

Absolute and proportional durations were taken, the latter as a function of the medial  $V(V)_1C(C)V_2$  sequence and of the whole word. The aim was to assess the degree to which the durations of each of  $V(V)_1$ ,  $C(C)$ , and  $V_2$  contribute to overall word duration and to the distinction between the four syllable structures, and to explore the mutual effect between medial  $C(C)$  duration and that of surrounding vowels. Note that the inclusion of  $V_2$  here is for descriptive purposes rather than any theoretical motivation around the adopted moraic analysis, which is more concerned with the phonetic implementation of the medial consonant and the preceding vowel.

## 6.2 Statistical design

To examine the contribution of each of the durational measurements to the distinction between the singleton and geminate consonants and the potential influence of the syllable structure on this contrast, three separate two-way ANOVAs<sup>7</sup> were run on the data using SPSS 19 (one on each of the consonantal parts  $C(C)$ , on the preceding vowel  $V(V)_1$ , and on the following vowel  $V_2$ ). Each ANOVA test was then followed by Bonferroni post-hoc analyses to reveal the contribution of each level of the independent variables separately to the model. Two measures of effect size are provided: the omega-squared measures ( $\omega^2$ ) for the omnibus ANOVAs, and Cohen's  $d$  for the post-hoc analyses.<sup>8</sup> These effect size measures make it possible to show the degree to which a significant difference is really important in distinguishing between singleton and geminate targets. Highly significant differences were expected due to the nature of the data that were obtained (short and long consonants and vowels, high number of speakers and tokens, etc.). Using effect size measure therefore made it possible to understand the contribution of a difference to the whole model.

<sup>7</sup> We checked the normality and the homogeneity of variance of our data, and although in most cases the data were not normally distributed, we are confident of the statistics reported here because of the high number of observations (e.g., Field 2009).

<sup>8</sup> Omega-squared ( $\omega^2$ ) is an unbiased measure of strength of association. It estimates how much of the variance associated with the dependent variable(s) can be explained by the independent variable(s) in the whole population. The range of  $\omega^2$  is from 0 to 1.  $\omega^2$  value is 'large' (L) when over .15, 'moderate' (M) when between .06 to .15, and 'small' (S) otherwise (Cohen 1988). An  $\omega^2$  value of .17 means that 17% of the variance in the dependent variable(s) was accounted for by the independent variable(s), and can be considered as a large effect using Cohen's benchmarks. Cohen's  $d$  effect size measure can be used when comparing only two groups. Cohen's  $d$  value is 'large' when over .8, 'moderate' when between .5 to .8, and 'small' otherwise (Cohen 1988).

Two factors were included in each ANOVA: Syllable Structure ( $V_1CV_2$ ,  $V_1CCV_2$ ,  $VV_1CV_2$ ,  $VV_1CCV_2$ ) and Manner of Articulation (approximants, fricatives, lateral, nasals, rhotic, stops).<sup>9</sup> The dependent variables in each ANOVA were: Absolute Duration, Proportional Duration Relative to the  $V(V)_1C(C)V_2$  Syllable, and Proportional Duration Relative to the Whole Word.

In addition, in order to evaluate the robustness of the differences observed in the ANOVAs between singleton and geminate consonants, we carried out several linear discriminant analysis (LDA) procedures. LDA predicts the strength of the differences obtained that might enable grouping of data. The higher the significant differences and the effect size, the stronger the grouping coefficients are (i.e., higher classification rates will be obtained from highly significant differences that have high effect size).

The grouping variable in each LDA was either Syllable Structure or Manner of Articulation, and the independent variables (or predictors) were the three durational measurements. For data classification, the leave-one-out method was used for cross-validation. This method classifies each case by the functions derived from all the cases (or groups) other than that case. While the ANOVA may show significant differences between the groups, the LDA shows if any of these differences enables the grouping of these variables. Results from the LDA will be reported as the proportion of variance explained and the percentage of correctly classified data.

## 7 Results

### 7.1 General results

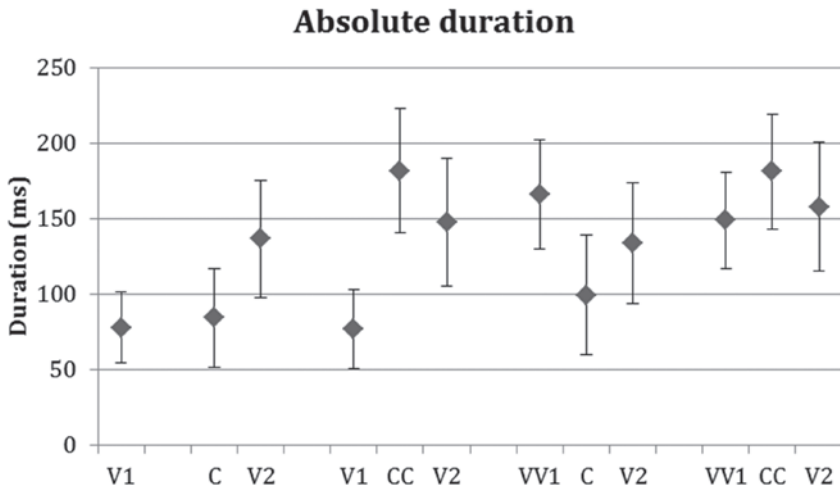
Statistical results obtained from the three omnibus two-way ANOVAs are presented in Table 2. These show that the four syllable structures can be distinguished significantly for each of  $V(V)_1$ ,  $C(C)$ , or  $V_2$ , based on each of the three durational measures, and that this factor contributed very highly to the model (see  $F$  value and  $\omega^2$  values). Manner of Articulation and the two-way interaction (Syllable Structure \* Manner of Articulation) were also differentiated significantly based on durational measures, but with lower  $F$  values and a smaller effect size.

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<sup>9</sup> Gender and speaker differences were not accounted for in this study. We ran separate four-way ANOVAs with syllable structure, manner of articulation, gender, and speaker as independent variables, and all three-way and four-way interactions were not significant. These non-significant results suggest that, regardless of their gender or individuality, all speakers produce the four syllabic shapes in the same manner across manners of articulation.

**Table 2:** Results of the three separate two-way ANOVAs. The abbreviations are the following: SS = Syllable Structure, MOA = Manner of Articulation, S = small effect, M = moderate effect, L = large effect, \*\*\*  $p < .0001$

C/V	Factors	df	Absolute			Proportional V(V)C(C)V			Proportional Word		
			F <sub>value</sub>	P <sub>value</sub>	$\omega^2$	F <sub>value</sub>	P <sub>value</sub>	$\omega^2$	F <sub>value</sub>	P <sub>value</sub>	$\omega^2$
V(V) <sub>1</sub>	SS	3, 5170	2257.45	***	.353(L)	2264.17	***	.345(L)	1901.79	***	.332(L)
	MOA	5, 5170	96.31	***	.028(S)	244.79	***	.069(S-M)	177.81	***	.057(S-M)
	SS*MOA	14, 5170	5.86	***	.004(S)	21.90	***	.017(S)	9.11	***	.007(S)
C(C)	SS	3, 5170	2234.21	***	.288(L)	1492.82	***	.276(L)	1489.93	***	.266(L)
	MOA	5, 5170	591.89	***	.137(M-L)	377.08	***	.125(M-L)	415.81	***	.132(M-L)
	SS*MOA	14, 5170	22.23	***	.014(S)	29.50	***	.027(S)	14.06	***	.012(S)
V(V) <sub>2</sub>	SS	3, 5170	45.25	***	.023(S)	581.09	***	.195(L)	73.52	***	.037(S)
	MOA	5, 5170	31.98	***	.027(S)	51.08	***	.030(S)	60.32	***	.050(S)
	SS*MOA	14, 5170	3.70	***	.007(S)	9.66	***	.014(S)	5.25	***	.010(S)



**Fig. 6:** Mean absolute duration and *SD* results for all speakers in each of the five syllable structures.

## 7.2 Absolute duration results

Figure 6 shows the mean and standard deviation (*SD*) results for the absolute duration of  $V(V_1)$ ,  $C(C)$ , and  $V_2$  in each of the four syllable structures for all speakers. Looking at  $V(V_1)$  first, absolute duration enabled the distinction between the four syllable structures in the omnibus ANOVA, with a large effect size (Table 2). Bonferroni post-hoc statistics enabled comparison between comparable syllable structures. For short  $V_1$ , there was no significant difference in the absolute duration of this vowel between  ${}^1V_1CCV_2$  ( $M = 78$  ms,  $SD = 23$ ) and  ${}^1V_1CV_2$  ( $M = 77$  ms,  $SD = 26$ ) ( $p = 1$ ,  $d = .05$  (S)), whereas in the long vowel context,  $VV_1$  is significantly longer with moderate effect in  ${}^{VV}V_1CV_2$  ( $M = 166$  ms,  $SD = 36$ ) than in  ${}^{VV}V_1CCV_2$  ( $M = 149$  ms,  $SD = 32$ ) ( $p < .0001$ ,  $d = .49$  (M)). On average, the ratio of  $V_1$  to  $VV_1$  is 1 to 2.10 in singleton contexts and 1 to 1.91 in geminate contexts, with no overlap between the distributions of short and long target vowels (Tables 3 and 4).

Moving on to  $C(C)$ , there is a clear durational difference between the geminate consonants in  ${}^1V_1CCV_2$  and  ${}^1VV_1CCV_2$  and their singleton counterparts in  ${}^1V_1CV_2$  and  ${}^1VV_1CV_2$ , respectively, with no overlap between the geminate-singleton distributions, suggesting that duration is a strong distinguishing cue for the singleton-geminate contrast (Table 3). Bonferroni post-hoc results show that  $C(C)$  duration is generally longer than  $V(V_1)$ , especially in  ${}^{VV}V_1CCV_2$  contexts (see Figure 6). The ratio of  $C$  to  $CC$  is 1 to 2.15 in short vowel contexts and 1 to 1.82 in long

**Table 3:** Mean duration (in ms) and standard deviations (in parentheses) for vowels and consonants in the four trochaic syllable structures, and for the whole word.

$V_1CV_2$			$V_1CCV_2$			$VV_1CV_2$			$VV_1CCV_2$		
$V_1$	C	$V_2$	$V_1$	CC	$V_2$	$VV_1$	C	$V_2$	$VV_1$	CC	$V_2$
78	84	137	77	182	147	166	99	134	149	181	158
(23)	(33)	(39)	(26)	(41)	(42)	(36)	(39)	(40)	(32)	(38)	(43)
$V_1CV_2 = 284 (24.8)$			$V_1CCV_2 = 390.3 (25.2)$			$VV_1CV_2 = 361.2 (24.4)$			$VV_1CCV_2 = 469.8 (29.2)$		

**Table 4:** Ratios of medial C to CC and  $V_1$  to  $VV_1$ .

Ratio of C to CC	V1 contexts 1:2.15	VV1 contexts 1:1.82
Ratio of $V_1$ to $VV_1$	C contexts 1:2.10	CC contexts 1:1.91

vowel contexts. However, this is not due to CC shortening in the long vowel context; instead, C duration was coincidentally longer in  $'VV_1CV_2$  ( $M = 99$  ms,  $SD = 39$ ) than in  $'V_1CV_2$  ( $M = 84$  ms,  $SD = 35$ ), with a moderate effect ( $p < .0001$ ,  $d = .42$  (M)). As expected, C duration in the geminate environments was significantly longer than in the singletons, with a very large effect size; C(C) in  $'V_1CV_2$  ( $M = 84$  ms,  $SD = 33$ ) and  $'V_1CCV_2$  ( $M = 182$  ms,  $SD = 41$ ) ( $p < .0001$ ,  $d = 2.64$  (L)) and C(C) in  $'VV_1CV_2$  ( $M = 99$  ms,  $SD = 39$ ) and  $'VV_1CCV_2$  ( $M = 181$  ms,  $SD = 38$ ) ( $p < .0001$ , Cohen's  $d = 2.11$  (L)). Unlike  $V(V)_1$ , there is no significant difference between CC in  $'V_1CCV_2$  ( $M = 182$  ms,  $SD = 41$ ) and  $'VV_1CCV_2$  ( $M = 181$  ms,  $SD = 38$ ) ( $p = 1$ ,  $d = .01$  (S)); this result is interesting and will be revisited in the discussion.

Results of  $V_2$  duration show significant differences linked with syllable structure differences (see Tables 3 and 4).  $V_2$  duration seems to vary with C(C) length in that it is significantly longer in the geminate than the singleton context, with a small to moderate effect,  $'V_1CCV_2$  ( $M = 147$  ms,  $SD = 42$ ) compared with  $'V_1CV_2$  ( $M = 137$  ms,  $SD = 39$ ) ( $p < .0001$ ,  $d = .27$  (S-M)), and  $'VV_1CCV_2$  ( $M = 158$  ms,  $SD = 43$ ) compared with  $'VV_1CV_2$  ( $M = 134$  ms,  $SD = 40$ ), with a moderate to large effect, ( $p < .0001$ ,  $d = .58$ ).  $V(V)_1$  length only seems to affect  $V_2$  duration in the geminate CC context, whereby  $V_2$  is significantly longer with a small-to-moderate effect in  $'VV_1CCV_2$  ( $M = 158$ ,  $SD = 43$ ) compared with  $'V_1CCV_2$  ( $M = 147$  ms,  $SD = 42$ ) ( $p < .0001$ ,  $d = .25$  (S-M)), but this may be caused by the lack of a final consonant in the  $'VV_1CCV_2$  structure rather than due to  $VV_1$ . Note that  $V_2$  duration was

found to be phonetically long in all contexts despite the fact it is phonologically short and in an unstressed syllable position. This may be due to the word list effect.

Looking at the overall V-C-V duration in the four syllable structures (Table 3), there are three groups of durations reflecting both phonological length and shortening where relevant: when both  $V_1$  and C are phonologically short, the mean duration for that sequence is around 300 ms. When either the vowel or the consonant is phonologically long, the sequence duration is around 400 ms, and when both are long the duration is around 500 ms. The duration of the V-C-V sequence in the fourth syllable structure provides argument for different weight in this structure compared with sequences where either the consonant or the vowel is phonologically long, potentially supporting the existence of superheavy syllables in LA despite the slight  $VV_1$  shortening.

### 7.3 Proportional duration results

In terms of proportional duration (Figure 7), i.e., duration of V(V) and C(C) either as a proportion of the medial V-C-V sequence (Figure 7, top) or of the word (Figure 7, bottom), the general patterns observed in absolute duration results still hold (also see Table 2 for statistical differences), but there is now evidence of temporal compensation between Vs and Cs depending on phonological length (only relevant statistics will be reported here). For instance,  $V_1$  in  $'V_1CCV_2$  contexts contributes a smaller proportion of the overall duration compared with  $V_1$  in  $'V_1CV_2$  contexts relative to both the word with a moderate effect ( $p < .0001$ ,  $d = .55$  (M)) and to the V-C-V sequence with a large effect ( $p < .0001$ ,  $d = 1.1$  (L)). Note that this is due to the length of the medial CC, not  $V_1$  shortening ( $V_1$  has comparable absolute durations in  $'V_1CV_2$  and  $'V_1CCV_2$  contexts, cf. Section 7.2), so any potential percept of shorter vowels in  $'V_1CCV_2$  would be due to the near-doubling of consonant length. Similarly, medial C in  $'VV_1CV_2$  occupies a smaller proportional duration than in  $'V_1CV_2$  contexts only in V-C-V sequence with a moderate effect size ( $p < .0001$ ,  $d = .36$  (M)), but this is once again due to the longer  $VV_1$  in the former context, not shorter consonant length; no differences are observed in the proportional duration relative to the word ( $p = 1$ ,  $d = .003$  (S)).

In the  $'VV_1CCV_2$  context, both  $VV_1$  and CC occupy a smaller proportional duration with moderate to large effect, compared with contexts where only the first vowel or the consonant is long:  $VV_1$  in  $'VV_1CCV_2$  is proportionally shorter than in  $'VV_1CV_2$  (in V-C-V sequence,  $p < .0001$ ,  $d = 1.55$  (L) and in word context,  $p < .0001$ ,  $d = .72$  (M-L)), and CC in  $'VV_1CCV_2$  is proportionally shorter than in  $'V_1CCV_2$  (in V-C-V sequence,  $p < .0001$ ,  $d = .95$  (L) and in word context,  $p < .0001$ ,  $d = .26$  (M)).

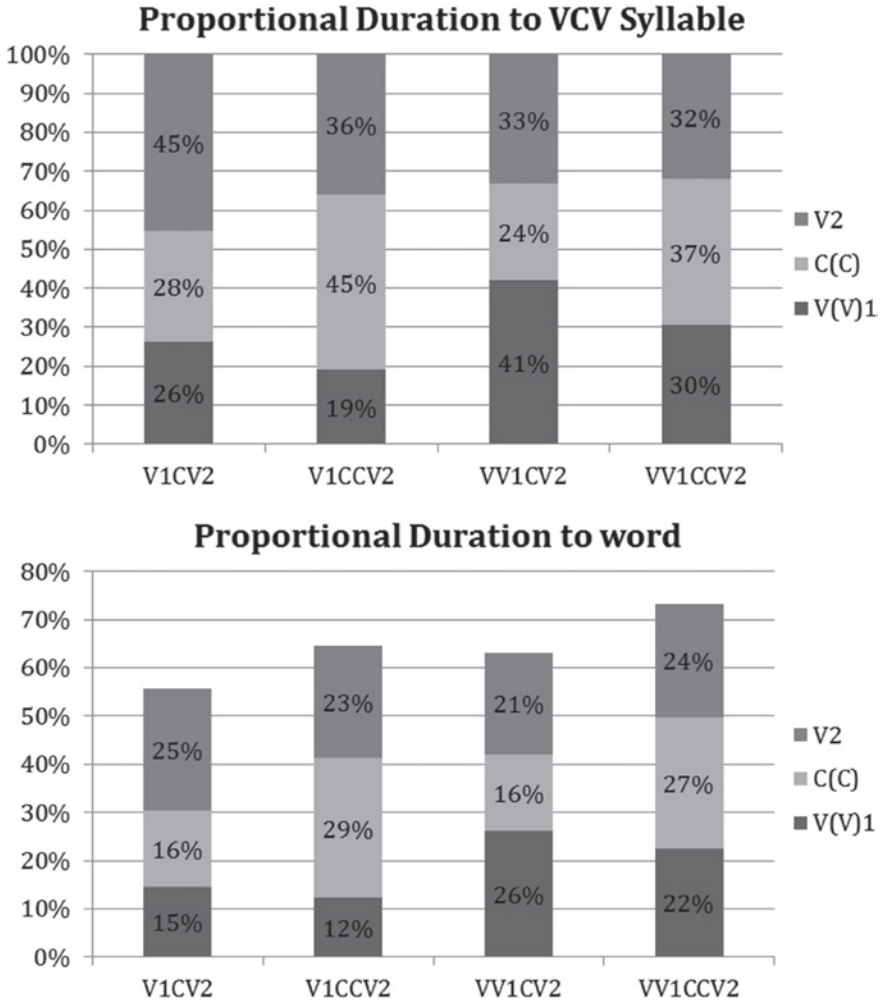


Fig. 7: Mean proportional duration for vowels and consonants in each of the four syllable structures as a proportion of the medial VCV sequence (top) or the whole word (bottom).

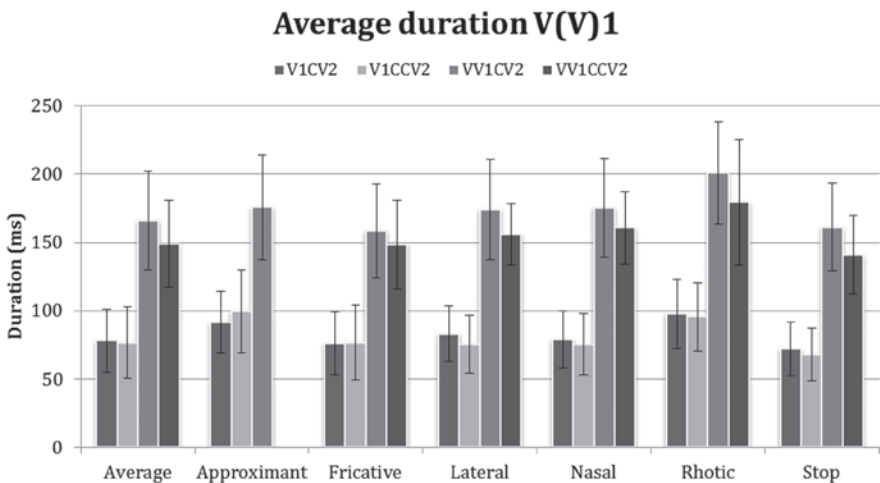
As for  $V_2$ , its proportional length seems to vary as a proportion of both  $V(V)_1$  and  $C(C)$  length. When proportions are obtained as a function of the V-C-V sequence (Figure 7, top),  $V_2$  is proportionally shortest when both  $V_1$  and  $C$  are phonologically long (i.e., in 'VV<sub>1</sub>CCV<sub>2</sub>'), with moderate to high effect (in all cases,  $p < .0001$ ,  $d$  from  $< .17$  to  $> .8$ ), and longest when they are short, with very high effect (in all cases,  $p < .0001$ ,  $d$  from  $> .8$ ). When proportional duration relative to the word is considered (Figure 7, bottom), the same pattern is observed in the first

two syllable structures, i.e.,  $V_2$  is shorter in  $'VV_1CV_2$  and  $'V_1CCV_2$  than in  $'V_1CCV_2$  ( $p < .0001$ ,  $d = .29$  (S–M)); however, the fourth syllable structure is not comparable with the others here due to  $VV_1CCV_2$  words having no final consonant.

Results from proportional durations suggest that the percept of a phonologically longer vowel or consonant does not necessarily require a neighbouring sound to shorten, but is rather achieved solely through lengthening of the segment itself, which leads it to occupy a larger proportion within the syllable or the word. This echoes findings that suggest that the primary cue for gemination is the duration of the consonant itself (Lahiri and Hankamer 1988; Esposito and Di Benedetto 1999; Arvaniti and Tserdanelis 2000; Ham 2001; Ladd and Scobbie 2004; Idemaru and Guion 2008; Ridouane 2010).

## 7.4 Interaction between Syllable Structure and Manner of Articulation

Figures 8, 9, and 10 show durational results for  $V(V)_1$ ,  $C(C)$ , and  $V(V)_2$ , respectively, as a function of the different manners of articulation of the medial consonant.<sup>10</sup> Starting with  $V_1$  (Figure 8), the omnibus ANOVA reveals a significant two-

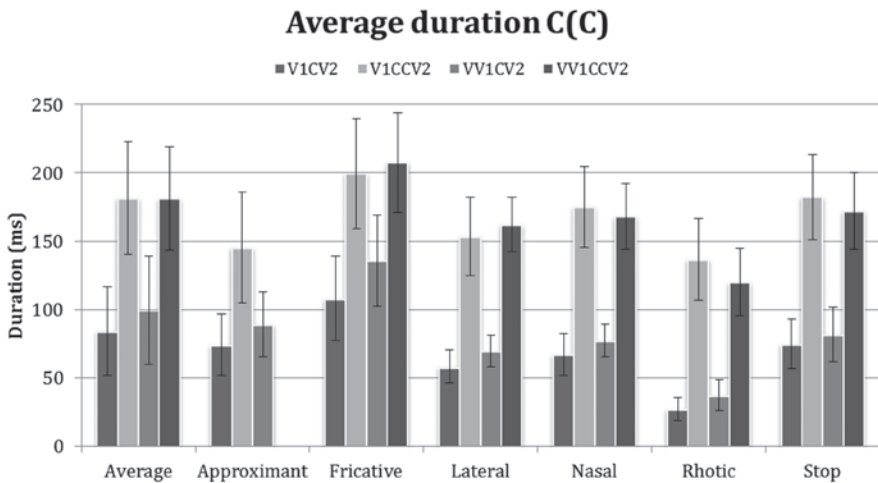


**Fig. 8:** Mean duration (in ms) and standard deviations for  $V(V)_1$  in each of the consonant categories.

<sup>10</sup> Only results obtained from absolute durations are presented here, as the same patterns were observed with proportional durations relative to the V-C-V sequence or to the whole word.

way interaction between Syllable Structure and Manner of Articulation, with a small effect size (Table 2). The general pattern for separate distributions for  $V_1$  in short and long targets is maintained for all categories, with the longest vowels found in 'VV<sub>1</sub>CV<sub>2</sub> structure with a moderate effect size (in all cases,  $p < .0001$ ,  $d > .29$  and  $< .66$  (M)). Rhotics and approximants were preceded by the longest vowels and fricatives and stops by the shortest vowels, with a moderate to large effect size, which shows an interaction between V(V), and C(C) whereby intrinsic consonant length triggers a shorter preceding vowel (in all cases,  $p < .0001$ ,  $d > .8$ ). This type of temporal compensation is related to manner of articulation and is independent of the phonological length of the medial consonant or its preceding vowel.

Moving to the medial C(C) (Figure 9 and Table 5), the omnibus ANOVA revealed a significant interaction of Syllable Structure and Manner of Articulation with a small effect size (Table 2). Bonferroni post-hoc analyses showed that the general patterns still hold across manners of articulation, i.e., medial consonants in geminate environments are significantly longer than medial consonants in singleton environments, with very large effect size (in all cases,  $p < .0001$ ,  $d > 2.2$  (L)). The comparison between Manner of Articulation in interaction with Syllable Structure revealed that in short C contexts ('V<sub>1</sub>CV<sub>2</sub> and 'VV<sub>1</sub>CV<sub>2</sub>), the shortest consonants are taps, followed by laterals, nasals, and approximants, and the longest are stops and fricatives (in all cases,  $p < .0001$ ,  $d > .8$ ). In long CC contexts, the order is more or less the same, although approximants are shorter than nasals



**Fig. 9:** Mean duration (in ms) and standard deviations for C(C) in each of the consonant categories.

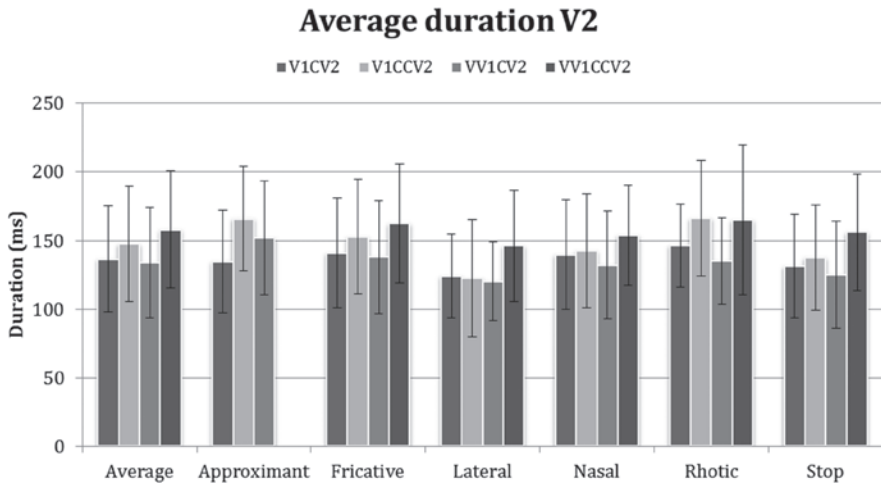
**Table 5:** Ratio of C to CC in each of the consonant categories.

	Ratio of C to CC in short V contexts	Ratio of C to CC in long VV contexts
Stops	1:2.44	1:2.10
Fricatives	1:1.85	1:1.53
Nasals	1:2.60	1:2.17
Laterals	1:2.64	1:2.34
Rhotics	1:5.04	1:3.21
Approximants	1:1.96	n/a
<b>Mean<sup>11</sup></b>	<b>1:2.15</b>	<b>1:1.82</b>

and laterals (in all cases,  $p < .0001$ ,  $d > -.8$ ). When looking at the ratio of singleton to geminate consonants (Table 5), it is the shortest consonants that produce the highest ratios, with liquids and nasals showing the greatest difference in duration between singleton and geminate targets, while the shortest durational difference was found between singleton and geminate fricatives. Within the approximant category, glides had surprisingly robust singleton-to-geminate ratios, suggesting that a durational contrast is still achievable in this supposedly inherently short category of sounds. One interesting observation from our data relates to the occasional realisation of taps (treated here as singletons) and trills (treated here as geminates) as approximants, especially by females, which led to longer duration for these segments than would be expected of the targets. This realisation has been reported before (Khattab 2002) and relates to social and linguistic variation in /r/ realisation in LA.

As for  $V_2$  (Figure 10), the omnibus ANOVA reveals a significant two-way interaction between Syllable Structure and Manner of Articulation, with a small effect size (Table 2). Overall results suggested that  $V_2$  was significantly longer in geminate environments compared to singletons (see sections 7.2 and 7.3). When comparing results by manner of articulation, the same general patterns still hold, mainly in the long  $VV_1$  environments, with  $V_2$  significantly longer in  $'VV_1CCV_2$  compared to  $V_2$  in  $'VV_1CV_2$  with moderate effect (in all cases,  $p < .0001$ ,  $d > .58$  and  $< .8$ ). In  $V_1$  environments, in all manners of articulation but laterals, nasal, and stops,  $V_2$  was significantly longer in  $'V_1CCV_2$  compared to  $V_2$  in  $'V_1CV_2$  with moderate to large effect (in all cases,  $p < .0001$ ,  $d > .28$  and  $< .85$ ). Also within this environment,  $V_2$  duration was the shortest in lateral, stop, and fricative envi-

<sup>11</sup> The mean value reported here is the arithmetic mean obtained from the pooled data across all manners of articulation.



**Fig. 10:** Mean duration (in ms) and standard deviations for  $V(V)_2$  in each of the consonant categories.

ronments, and longest following nasals and rhotics, with moderate to large effect sizes (in all cases,  $p < .0001$ ,  $d > .5$  and  $< .1$ ); in  $VV_1$  environments,  $V_2$  was the shortest following laterals and longest following approximants, fricatives, and rhotics, with moderate to large effect sizes (in all cases,  $p < .0001$ ,  $d > .5$  and  $< .1$ ).

## 7.5 Discriminant analysis

Each of the two-way ANOVAs was followed by separate LDAs.<sup>12</sup> Several LDAs for each of  $V(V)_1$ ,  $C(C)$ , or  $V_2$  were performed on the Durational Measures as predictors and Syllable Structures as grouping variables.

Looking at Syllable Structures, the grouping variable, we present the results in Table 6 for each of  $V(V)_1$ ,  $C(C)$ , or  $V_2$ . This table shows the degree to which the

<sup>12</sup> Two additional LDAs were performed with Gender and Speaker as predictors. The overall LDA classification results were very poor in the discrimination between Males and Females or between speakers, showing that these factors cannot be significantly differentiated using any of the durational measures. LDA results by manner of articulation revealed high classification results at around 40%, showing that the ANOVA results obtained in this study were robust, i.e., durational measurements were not sufficient in discriminating the manner of articulation. Thus, only results of the LDAs by syllable structure and by separating the classification results by manner of articulation will be reported here.

**Table 6:** LDA results for syllable structure as a grouping variable, for each of  $V(V)_1$ ,  $C(C)$ , or  $V(V)_2$ . Under discriminant function(s), this indicates the number of dimensions used (three in this case) and how much of the variance the combination of the three dimensions, the second and third combined, and only the third is explained by these dimensions.

C/V	Discriminant functions	Wilks's $\lambda$	$\chi^2$	df	$P_{\text{value}}$	$R^2$
$V(V)_1$	3: all = 73.2%	.195	8443.56	9	<.0001	.814
	2 + 3 = 26.5%	.579	2827.26	4	<.0001	.645
	3 = .4%	.990	52.76	1	<.0001	.101
$C(C)$	3: all = 78.6%	.288	6431.49	9	<.0001	.772
	2 + 3 = 21.1%	.712	1754.28	4	<.0001	.533
	3 = .3%	.994	31.20	1	<.0001	.078
$V(V)_2$	3: all = 98.4%	.325	5805.81	9	<.0001	.815
	2 + 3 = 1.6%	.968	166.69	4	<.0001	.176
	3 = .0%	.999	3.68	1	=.055	.027

LDAs are successful in discriminating the groups, by indicating the significance level of each discriminant function, the number of dimensions used to discriminate between the four syllable structures, and how much of the variance is explained by each dimension. For  $V(V)_1$ , the three durational measures were correlated with the first discriminant function, and absolute duration was used as the first predictor in the classification, followed by proportional duration relative to the V-C-V sequence and then by proportional duration relative to the whole word. For  $C(C)$ , absolute duration and proportional duration relative to the whole word were correlated with the first discriminant function and were used as main predictors. Proportional duration relative to the V-C-V sequence was correlated with the second discriminant function. And finally, for  $V(V)_2$ , the three durational measures were correlated with the second discriminant function, and the proportional duration relative to the whole word was used as the first predictor, followed by the absolute duration and finally proportional duration relative to the V-C-V sequence.

Classification rates obtained from the separate LDAs were relatively high with some confusion, mainly between syllabic shapes with compatible  $V_1$  and/or C length (Table 7). For  $V(V)_1$ , classification rates with cross-validation were 75.7% with some confusion, mostly between  $'V_1CV_2$  and  $'V_1CCV_2$ , or between  $VV_1CV_2$  and  $VV_1CCV_2$  (Table 7). For  $C(C)$ , classification rates were 68.2%, with confusions between  $'V_1CV_2$  and  $VV_1CV_2$ , or between  $'V_1CCV_2$  and  $VV_1CCV_2$  (Table 8), and finally for  $V_2$ , they were at 60.2% with confusions, especially between  $'V_1CCV_2$ ,  $VV_1CV_2$ , and  $VV_1CCV_2$ ;  $'V_1CV_2$  was the only syllable struc-

**Table 7:** Confusion matrices in the classification of syllable structures in  $V(V)_1$ ,  $C(C)$ , and  $V_2$  contexts. The numbers show the percentage of correct classification of each grouping variable as a function of the predicted Group Membership.

	Syllable Structure	Predicted Group Membership				Total
		V1CV2	V1CCV2	VV1CV2	VV1CCV2	
$V(V)_1$	V1CV2	<b>72.4%</b>	24.2%	3.0%	.5%	100%
	V1CCV2	8.8%	<b>85.4%</b>	1.8%	4.0%	100%
	VV1CV2	9.3%	2.4%	<b>72.7%</b>	15.6%	100%
	VV1CCV2	3.6%	16.3%	12.8%	<b>67.3%</b>	100%
$C(C)$	V1CV2	<b>74.3%</b>	7.7%	17.9%	.1%	100%
	V1CCV2	7.1%	<b>72.6%</b>	7.2%	13.0%	100%
	VV1CV2	17.6%	12.8%	<b>62.1%</b>	7.4%	100%
	VV1CCV2	1.2%	28.1%	13.5%	<b>57.2%</b>	100%
$V_2$	V1CV2	<b>86.4%</b>	9.3%	4.3%	.0%	100%
	V1CCV2	8.3%	<b>58.0%</b>	26.7%	7.1%	100%
	VV1CV2	6.8%	46.2%	<b>38.9%</b>	8.0%	100%
	VV1CCV2	.0%	30.0%	21.5%	<b>48.5%</b>	100%

**Table 8:** Classification rates of syllable structure as a grouping variable in  $V(V)_1$ ,  $C(C)$ , and  $V_2$  contexts by manner of articulation.

	$V(V)_1$	$C(C)$	$V_2$
Overall	75.7%	68.2%	60.2%
Approximant	83.3%	81.1%	68.0%
Fricative	74.7%	70.4%	65.5%
Lateral	89.3%	85.3%	63.5%
Nasal	85.1%	80.6%	65.7%
Rhotic	89.4%	84.5%	68.2%
Stop	84.9%	78.4%	64.1%

ture with very high classification rate at 86.4% with very little confusion (see Table 8).

Overall, these results are compatible with what was presented in the previous sections, with main confusions linked to compatible syllabic shapes on either  $V_1$  or  $C$ .

When LDA was carried out on the interaction between syllable structure and manner of articulation, the overall results stood again, and the classification rates were slightly higher than those obtained without any specification of the manner of articulation (Table 8). The confusion matrices in the classification by

manner of articulation were almost the same as reported earlier in this section but with less confusion.

## 8 Summary of results

Here we revisit the research questions and the predictions that we made in Section 5. With respect to the temporal manifestations of the singleton-geminate contrast in LA, geminate consonants were found to be twice as long as their singleton counterparts, with no overlap between the singleton and geminate ranges. Phonologically long vowels were also found to be twice as long as their short counterparts. Vowels were in general phonetically shorter than consonants, and occupied smaller proportions of the V-C-V sequence and the word. When the different consonant manners of articulation were looked at, the singleton-to-geminate ratio ranged from 1:1.85 in fricatives to 1:2.64 in laterals in the short vowel context (rhotics are excluded here). The patterns that were exhibited in the four syllable structures across all consonants remained very stable in each of the manners of articulation that were examined. LDA showed very good classification of  $V(V)_1$ , C(C), or  $V_2$  across the four syllable structures, with main confusions linked to vowels or consonants with compatible phonological length.

In terms of the predicted variation in the duration of  $V(V)_1$  and CC across the four syllable structures, predictions 1 and 2 were confirmed. Vowel duration in the four syllable structures showed the following pattern:  $VV_1$  (166 ms) >  $VV_1C$  (149 ms) >  $V_1$  (78 ms) =  $V_1C$  (77 ms), supporting a mora-based account of timing in LA. As for prediction 3, medial CC duration was not found to be affected by the phonological length of the preceding vowel, with  $V_1CC$  (182 ms) =  $VV_1CC$  (181 ms). While we had no specific predictions for  $V_2$ , it was found to be consistently longer in geminate than in singleton environments. Proportional durations as a function of the word or the V-C-V sequence show that the presence of a phonologically long segment leads to a proportionally shorter neighbour; this is driven by the duration of the target long segment, and no actual shortening of surrounding segments occurs apart from the long vowel in  $VV_1CCV_2$ .

## 9 Discussion

This study looked at vowel and medial consonant duration in four syllable structures in LA; the aim was to explore the way singleton and geminate consonants pattern with surrounding vowels and the implications this has for phonological structure, in particular suprasegmental representation and weight distribution.

A moraic view of timing was tested due to the fact that Moraic Theory has been shown to account for various aspects of stress and syllable structure in Arabic (e.g., Broselow et al. 1997; Watson 2007; Davis and Ragheb to appear), but also due to its ability to yield different predictions for phonetic behaviour of short and long vowels when preceding geminate consonants.

Duration in LA was found to be a robust cue for phonological consonant and vowel length, with the distributions for short and long consonants and vowels showing no overlap. This is not entirely surprising when considering the fact that quantity distinctions between vowels and consonants play an important role in Arabic morphology (McCarthy 1981). It is, however, important to bear in mind that duration is not the only cue for the distinction between short and long consonants and vowels in Lebanese Arabic; the rates of classification of the Discriminant Analyses reported earlier do not show a 100% classification rate, and there are other non-temporal cues to the distinction between singleton and geminate consonants (Al-Tamimi and Khattab 2011, under review). Moreover, LA seems to pattern with the group of languages that have a 2 to 1 rather than 3 to 1 ratio between singleton and geminate consonants.

As reported elsewhere, sonorants showed the highest singleton-to-geminate ratios, which may help to explain their frequency as geminates in many languages (e.g., Ohala 1983; Blevins 2004; though see Kawahara et al. [2011] for arguments against the frequency of sonorants, highlighting their confusability with neighbouring vowels). While fricatives were amongst the longest consonants, their singleton-to-geminate ratios were relatively less distinct, mostly due to the sibilants in this category, which had long singletons; this may reduce the percept of a phonological length contrast for this class of sounds and explain why sibilants are susceptible to de-gemination types (Tserdanelis and Arvaniti 2001; Blevins 2004; Aoyama and Reid 2006). Taps and trills have been included here, although we acknowledge that the contrast between them involves a lot more than duration and that they may involve lengthening of the previous vowel. Our reported results, however, remained robust even after removing rhotics from the data. Moreover, the durational contrast in singleton and geminate /w/ was robust and had comparable ratios to the other categories of sounds, supporting Maddieson's (2007) view that geminate glides are not rare because of their short duration, but probably because their margins are poorly defined. Indeed, labelling /w/ and /j/ in this study was tricky due to the difficulty in deciding on their margins with the surrounding vowels, but they showed distinct phonologically short and long durations.

The durational results obtained in this study support mora-based timing for LA. This was shown in the different predictions for  $V_1$  and medial C(C) duration in the four syllable structures that were examined: first,  $V_1$  showed no evidence

of shortening in a closed syllable context ( $'V_1C.CV_2$ ) compared with an open one ( $'V_1.CV_2$ ). This suggests that phonetic timing in this case is determined by weight that is mora-based rather than influenced by syllable structure, as  $V_1$  duration does not seem to be affected by its proximity to a coda consonant in  $'V_1C.CV_2$ . This also suggests that  $V_1$  duration does not provide very useful information for consonant quantity, although proportional durations (Figure 7) did show that  $V_1$  contributes a smaller proportion of the overall duration of the word when the following consonant is a geminate. These results are similar to what is found for mora-timed language like Japanese (Idemaru and Guion 2008) whereby the consonant durational cue is sufficiently strong, rendering the duration of the preceding vowel less important for the singleton-geminate contrast. Syllable-timed languages, on the other hand (e.g., Italian or Madurese), are thought to have a less robust singleton-geminate durational difference and to show a durational inverse between the stop and the preceding vowel (e.g., Esposito and Di Benedetto 1999; Ham 2001).

Second, in the long  $VV_1$  context, the influence of both syllable and moraic structure can be seen, whereby  $VV_1$  in  $'VV_1.CV_2$  is longer than in  $'VV_1C.CV_2$ . Here, the bimoraic limit on syllable weight requires mora sharing between  $VV_1$  and  $CC$  in  $'VV_1C.CV_2$ , leading to a shorter  $VV_1$  than in  $'VV_1.CV_2$ . What is interesting here, though, is that  $CC$  did not shorten in  $'V_1CCV_2$  versus  $'VV_1CCV_2$ , showing that the effect of mora sharing only influenced the preceding vowel. This result sets medial geminates apart from medial clusters in LA, where the coda has been shown to shorten by around 31% (Broselow et al. 1997). This result also suggests that medial geminates in long  $VV_1$  contexts are not semi-geminates as Maddieson (1993: 14) suggests, but instead preserve their weight and duration.  $CC$  duration in LA seems to be more generally robust than  $VV$  duration and relatively less influenced by syllable constraints; this was shown in the generally longer  $C(C)$  than  $V(V)$  durations, and in the way  $C(C)$  influenced  $V_2$  duration more than  $V(V)_1$ . So while the moraic representations for words with medial clusters and geminate consonants following Adjunction-to-Mora are the same (Figures 2 and 3), the inherent weight in geminate consonants may play a role in these consonants resisting the shortening required to turn from trimoraic to bimoraic syllables. This might give internal  $VVC$  syllables with a medial geminate an intermediate status: they are longer than other bimoraic syllables in LA ( $VV_1$  and  $V_1C$ ), but show  $VV_1$  shortening. This might explain why  $'VV_1CCV_2$  structures have relatively low frequency in LA (Ham 2001).

Contrary to what has been reported in studies on other languages (e.g., Local and Simpson 1988; Aoyama 2001; Idemaru and Guion 2008),  $V_2$  duration was found to be longer in the geminate than in the singleton context ( $'V_1CCV_2$  compared with  $'V_1CV_2$ , and  $'VV_1CCV_2$  compared with  $'VV_1CV_2$ ). Local and Simpson ex-

plained the shorter  $V_2$  results that they found in the geminate context in terms of the rhythmic quantities of Malayalam, claiming that disyllables are equally weighted in geminate contexts whereas the first syllable is short and the second long in singleton contexts. In principle the same can be said to apply in this study, but with disyllables in the short C contexts having a long-short rhythm in the trochaic contexts looked at here while they have equal weight in the geminate contexts. This leads  $V_2$  to have relatively shorter duration in the singleton contexts and longer duration in the geminate contexts. The longer  $V_2$  in the geminate context could be playing a perceptual role of minimising the percept of  $V_1$  length, rendering  $V(V_1)$  proportionally shorter in geminate than singleton contexts. While the majority of studies concentrate on cues for the singleton-geminate contrast in the preceding vowel and the consonant itself, our results suggests that  $V_2$  duration may also offer secondary cues.

This study has shown that there is a relationship between phonological structure, moraic weight, and phonetic timing in LA, as demonstrated in the patterns found for segmental timing in medial geminate consonants and their surrounding vowels. Consonant and vowel duration in LA are governed by a combination of phonological length, syllable structure/position, and mora-based weight. In terms of phonological length, geminate consonants and phonologically long vowels are statistically longer than their singleton/short counterparts, and duration is a robust cue for the phonological contrast in each case. In terms of the prosodic hierarchy and the interaction between mora-based weight and syllable structure, the moraic representations suggested for LA in this study and adopted by Broselow et al. (1997: 76) seem to provide a valid reflection of syllable-weight oppositions in the four contexts examined here, and moraic structure is directly reflected in phonetic timing. This was shown in the way medial consonant and surrounding vowel duration patterned in each of the four syllable structures which showed the influence of mora-timing. Mora sharing in the case of geminate consonants and long vowels ( ${}^1VV_1CCV_2$  syllables) not only reflects a phonological relationship between geminate consonants and long vowels, but also a phonetic reality: this was the only context where  $VV_1$  showed shortening compared with  ${}^1VV_1CV_2$ , while remaining significantly longer than phonologically short  $V_1$ .

## 10 Conclusion

By adopting a prosodic template model for LA that uses a moraic approach to syllable structure, and by providing acoustic data on durational cues, our results exhibit convergence between phonological representation and phonetic

implementation. While mora-timing has often been found useful for the description of syllable weight in Arabic, the results in this study constitute the first set of quantitative evidence for systematic phonetic manifestations of the mora in the singleton-geminate contrast in LA, as was suggested for clusters by Broselow et al. (1997). Syllable position and mora-conditioned weight were found to be powerful in predicting phonetic timing for singleton and geminate consonants and their surrounding vowels, suggesting an effect of phonological structure, in this case a hierarchical suprasegmental representation that is governed by moraic weight, on phonetic timing (Hubbard 1995; Ham 2001; Cohn 2003). This is a step forward from Hayes' (1989) treatment of moras as abstract units which make no predictions about surface timing. Segmental structure is also clearly important, since non-moraic consonants also contribute to the physical duration, and intrinsic consonant length plays a role in the strength of the singleton-geminate contrast. This supports Ham's (2001) suggestion of the need to integrate both segmental and prosodic structure in any model of phonetic timing. Phonetic predictions, moreover, must also be language specific and under the control of the speaker, since the results from this study do not necessarily apply to other Arabic dialects (cf. Broselow et al. 1995; F. Al-Tamimi 2004) or other languages (Tranel 1991; Hume et al. 1997; Esposito and Di Benedetto 1999; Podesva 2000; Hassan 2002; Ringen and Vago 2011). As Ham (2001) points out, factors such as whether a language allows closed syllable shortening, whether there are constraints on quantity in VC sequences, or whether timing is syllable or mora based (as evidenced by temporal spacing between vowel onsets) all play a role.

While Moraic Theory predicts that syllables closed with a geminate always count as heavy, Broselow et al. (1997) point out that in some languages syllables closed with a geminate can still be considered light, e.g., Malayalam, where weight is entirely dependent on vowel length. It is therefore important to consider the role of syntagmatic and paradigmatic relations in the implementation of phonetic timing, as pointed out by Ham (2001) in his study of geminate timing in several languages. Ham (2001: 173) further suggests that some languages like Madurese follow syllable- rather than mora-timing, as the temporal interval between vowel onsets in this language is static. On the other hand, languages like Hindi are heavily moraic and allow a trimoraic syllable structure, which does not require mora-sharing in a <sup>l</sup>CVVC.CV(C) environment where the medial CC is a geminate (Broselow et al. 1997). These phonological patterns translate into different moraic representations of CVC and CVVC syllables across the different languages. It has been shown here that the prosodic hierarchy plays a major role in the implementation of phonetic timing; it is therefore important to consider language-specific strategies which emerge from the coordination of articulatory gestures for consonants and vowels.

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## References

- Abramson, Arthur. 1991. Amplitude as a cue to word-initial consonant length: Pattani Malay. In *Proceedings of the XIth International Congress of Phonetic Sciences (ICPhS)*, 98–101. Aix-en-Provence: Centre National de la Recherche Scientifique.
- Al-Tamimi, Feda Y. 2004. An experimental phonetic study of intervocalic singleton and geminate sonorants in Jordanian Arabic. *Al-Arabiyya* 29. 37–52.
- Al-Tamimi, Jalal, & Ghada Khattab. 2011. Multiple cues for the singleton-geminate contrast in Lebanese Arabic: Acoustic investigation of stops and fricatives. In Wai-Sum Lee & Eric Zee (eds.), *Proceedings of the 17<sup>th</sup> International Congress of Phonetic Sciences (ICPhS)*, 212–215. Hong Kong.
- Al-Tamimi, Jalal, & Ghada Khattab. under review. Acoustic cue weighting in the singleton vs geminate contrast in Lebanese Arabic: The case of fricative consonants.
- Aoyama, Katsura. 2001. *A psycholinguistic perspective on Finnish and Japanese prosody: Perception, production and child acquisition of consonantal quantity distinctions*. Norwell: Kluwer Academic Publishers Group.
- Aoyama, Katsura. 2002. Quantity contrasts in Japanese and Finnish: Differences in adult production and acquisition. In Yasuhiro Shirai, Harumi Kobayashi, Susanne Miyata, Keiko Nakamura, Tamiko Ogura, & Hidetosi Sirai (eds.), *Studies in Language Sciences (2): Papers from the Second Annual Conference of the Japanese Society for Language Sciences*, 121–135. Tokyo: Kuroshio.
- Aoyama, Katsura, & Lawrence A. Reid. 2006. Cross-linguistic tendencies and durational contrasts in geminate consonants: An examination of Guinaang Bontok geminates. *Journal of the International Phonetic Association* 36(2). 145–157.
- Arvaniti, Amalia. 1999. Effects of speaking rate on the timing of single and geminate sonorants. In *Proceedings of the XIVth International Congress of Phonetic Sciences*, 599–602. San Francisco, CA.
- Arvaniti, Amalia. 2001. Comparing the phonetics of single and geminate consonants in Cypriot and Standard Greek. *Proceedings of the 4th International Conference on Greek Linguistics*, 37–44. Thessaloniki: University Studio Press.
- Arvaniti, Amalia, & Georgios Tserdanelis. 2000. On the phonetics of geminates: evidence of Cypriot Greek. *Proceedings of 6th International Conference on Spoken Language Processing* 2. 559–562.
- Baker, Brett J. 2008. *Word structure in Ngalakgan*. Palo Alto, CA: Stanford University Center for the Study of Language and Information.
- Belasco, Simon. 1953. The influence of force of articulation of consonants on vowel duration. *Journal of the Acoustical Society of America* 25(5). 1015–1016.
- Blevins, Juliette. 2004. *Evolutionary phonology: the emergence of sound patterns*. Cambridge: Cambridge University Press.

- Boersma, Paul, & David Weenink. 2009. *Praat: Doing phonetics by computer* (Version 5.1.0) [Computer program]. <http://www.praat.org/> (accessed 22 July 2009).
- Broselow, Ellen. 1992. Parametric variation in Arabic dialect phonology. In Ellen Broselow, Mushira Eid, & John McCarthy (eds.), *Perspectives on Arabic Linguistics 4*, 7–45. Amsterdam and Philadelphia: John Benjamins.
- Broselow, Ellen. 1995. Skeletal positions and moras. In John Goldsmith (ed.), *The handbook of phonological theory*, 175–205. Cambridge, MA, and Oxford: Blackwell.
- Broselow, Ellen, Susan Chen, & Marie Huffman. 1997. Syllable weight: convergence of phonology and phonetics. *Phonology* 14. 47–82.
- Broselow, Ellen, Marie Huffman, Susan Chen, & Ruohmei Hsieh. 1995. The timing structure of CVVC syllables. In Mushira Eid (ed.), *Perspectives on Arabic Linguistics VII: Papers from the 7th Annual Symposium on Arabic Linguistics*, 119–138. Amsterdam and Philadelphia: John Benjamins.
- Catford, John C. 1977. *Fundamental problems in phonetics*. Bloomington: Indiana University Press.
- Chomsky, Noam, & Morris Halle. 1968. *The sound pattern of English*. New York: Harper and Row.
- Cohen, Jack. 1988. *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Cohn, Abigail. 2003. Phonological structure and phonetic duration: the role of the mora. *Working Papers of the Cornell Phonetics Laboratory* 15. 69–100.
- Cohn, Abigail, William Ham, & Robert Podesva. 1999. The phonetic realization of singleton-geminate contrasts in three languages of Indonesia. In John J. Ohala, Yoko Hasegawa, Manjari Ohala, Daniel Granville, & Ashlee C. Bailey (eds.), *Proceedings of the 14th International Congress of Phonetic Sciences*, 587–590. San Francisco, CA.
- Davis, Stuart. 1999. On the moraic representation of underlying geminates: Evidence from prosodic morphology. In René Kager, Harry van der Hulst, & Wim Zonneveld (eds.), *The prosody–morphology interface*, 39–61. Cambridge: Cambridge University Press.
- Davis, Stuart. 2011. Geminates. In Marc van Oostendorp, Colin J. Ewen, Elizabeth Hume, & Keren Rice (eds.), *The Blackwell Companion to Phonology*, Vol. 2, 837–859. Malden, MA, and Oxford: Wiley-Blackwell.
- Davis, Stuart, & Marwa Ragheb. To appear. Geminate representation in Arabic. In Samira Farwanah (ed.), *Perspectives on Arabic Linguistics 25*. Philadelphia/Amsterdam: John Benjamins Co.
- Esposito Anna, & Maria G. Di Benedetto. 1999. Acoustical and perceptual study of gemination in Italian stops. *Journal of the Acoustical Society of America* 106. 2051–2062.
- Farinas, Jérôme, Jean-Luc Rouas, François Pellegrino, & Régine André-Obrecht. 2005. Extraction automatique de paramètres prosodiques pour l'identification automatique des langues. *Traitement du Signal* 22 (2). 81–97.
- Field, Andy P. 2009. *Discovering statistics using SPSS: and sex and drugs and rock 'n' roll* (3rd ed.). London: Sage.
- Ghalib, Ghalib B. M. 1984. An experimental study of consonant gemination in Iraqi colloquial Arabic. University of Leeds Ph.D. thesis.
- Ham, William. 2001. *Phonetic and phonological aspects of geminate timing*. New York: Routledge.
- Hankamer, Jorge, Aditi Lahiri, & Jacques Koreman. 1989. Perception of consonant length: Voiceless stops in Turkish and Bengali. *Journal of Phonetics* 17(4). 283–298.

- Hansen, Benjamin B. 2003. Production of Persian geminate stops: Effects of varying speaking rate. In Augustine Agwuele, Willis Warren, & Sang-Hoon Park (eds.), *Proceedings of the 2003 Texas Linguistics Society Conference*. 86–95. Somerville, MA: Cascadilla Proceedings Project.
- Hassan, Zeki M. 2002. Gemination in Swedish and Arabic with a particular reference to the preceding vowel: an instrumental and comparative approach. In *Proceedings of Fonetik TMH-QPSR 44*. 81–85. Swedish Loredana Cerrato Centre for Speech Technology.
- Hassan, Zeki M. 2003. Temporal compensation between vowel and consonant in Swedish and Arabic in sequences of CV:C and CVC: and the word overall duration. *PHONUM* 9. 45–48.
- Hayes, Bruce. 1986. Inalterability in CV phonology. *Language* 62. 321–351.
- Hayes, Bruce. 1989. Compensatory lengthening in moraic phonology. *Linguistic Inquiry* 20. 253–306.
- Homma, Y. 1981. Durational relations between Japanese stops and vowels. *Journal of Phonetics* 9. 273–281.
- Hubbard, Kathleen. 1995. Toward a theory of phonological and phonetic timing: Evidence from Bantu. In *Phonological and Phonetic Evidence: Papers in Laboratory Phonology IV*, 168–187. Cambridge: CUP.
- Hume, Elizabeth, Jennifer Muller, & Aone van Engelenhoven. 1997. Non-moraic geminates in Leti. *Phonology* 14. 371–402.
- Hyman, Larry M. 1985. *A theory of phonological weight*. Foris: Dordrecht.
- Idemaru, Kaori, & Susan G. Guion. 2008. Acoustic covariants of length contrast in Japanese stops. *JIPA* 38. 167–186.
- Kawahara, Shigeto, Melanie Pangilinan, & Kelly Garvey. 2011. Spectral continuity and the perception of duration: Implications for phonological patterns of sonorant geminates. Rutgers University manuscript.
- Khattab, Ghada. 2002. /r/ production in English and Arabic bilingual and monolingual speakers. *Leeds Working Papers in Linguistics and Phonetics* 9. 91–129.
- Khattab, Ghada. 2007. A phonetic study of gemination in Lebanese Arabic. Special session on 'Arabic at the beginning of the 2<sup>nd</sup> Millennium'. In Jürgen Trouvain & William J. Barry (eds.), *Proceedings of the 16<sup>th</sup> International Congress of Phonetic Sciences*, 153–158. Saarbrücken.
- Khattab, Ghada, & Jalal Al-Tamimi. 2008. Durational cues for gemination in Lebanese Arabic. *Language and Linguistics* 22. 39–55.
- Kingston, John, Shigeto Kawahara, Della Chambless, Daniel Mash, & Eve Brenner-Alsop. 2009. Contextual effects on the perception of duration. *Journal of Phonetics* 37(3). 297–320.
- Kiparsky, Paul. 2003. Syllables and moras in Arabic. In Caroline Fery & Ruben van de Vijver (eds.), *The syllable in Optimality Theory*, 147–182. Cambridge: Cambridge University Press.
- Ladd, D. Robert, & Jim Scobbie. 2003. External sandhi as gestural overlap? Counter-evidence from Sardinian. In John Local, Richard Ogden, & Rosalind Temple (eds.), *Papers in Laboratory Phonology VI*, 164–182. Cambridge: Cambridge University Press.
- Ladefoged, Paul, & Ian Maddieson. 1996. *The sounds of the world's languages*. Oxford: Blackwell.
- Lahiri, Adithi, & Jorge Hankamer. 1988. The timing of geminate consonants. *Journal of Phonetics* 16. 327–338.

- Leben, William R. 1980. A metrical analysis of length. *Linguistic Inquiry* 11. 497–509.
- Lehiste, Ilse. 1971. Temporal organization of spoken language. In Louis L. Hammerich, Roman Jakobson, & Eberhard Zwirner (eds.), *Form and substance: Phonetic and linguistic papers presented to Eli Fischer-Jørgensen*, 159–169. Akademisk Forlag.
- Local, John, & Adrian Simpson. 1988. The domain of gemination in Malayalam. In David Bradley, Eugenie J. A. Henderson, & Martine Mazaudon (eds.), *Prosodic analysis and Asian Linguistics: To honour R. K. Sprigg*, 33–42. Pacific Linguistics Series C 104.
- Local, John, & Adrian Simpson. 1999. Phonetic implementation of geminates in Malayalam nouns. In John J. Ohala, Yoko Hasegawa, Manjari Ohala, Daniel Granville, & Ashlee C. Bailey (eds.), *Proceedings of the 14<sup>th</sup> International Congress of Phonetic Sciences*, Vol. 1, 595–598. San Francisco, CA.
- Maddieson, I. 1993. Splitting the mora. *UCLA Working Papers in Phonetics* 83. 9–18.
- Maddieson, Ian. 1997. Phonetic universals. In William J. Hardcastle & John Laver (eds.), *The Handbook of Phonetic Sciences*, 619–639. Oxford: Blackwell.
- Maddieson, Ian. 2007. Glides and gemination. *Lingua* 118(12). 1926–1936.
- McCarthy, John J. 1979. Formal problems in Semitic phonology and morphology. Cambridge, MA: MIT Ph.D. dissertation.
- McCarthy, John J. 1981. A prosodic theory of non-concatenative morphology. *Linguistic Inquiry* 12. 373–418.
- McCarthy, John J. 1986. OCP effects: Gemination and antigemination. *Linguistic Inquiry* 17. 207–263.
- McCarthy, John J. 1988. Feature geometry and dependency: a review. *Phonetica* 45. 84–108.
- McCarthy, John J., & Alan Prince. 1990. Foot and word in prosodic morphology: the Arabic broken plural. *Linguistic Enquiry* 8. 209–283.
- McCarthy, John J., & Alan Prince. 1995. Prosodic morphology. In John Goldsmith (ed.), *Handbook of Phonological Theory*, 318–366. Blackwell: Oxford.
- McKay, Graham Richard. 1980. Medial stop gemination in Rembarrnga: A spectrographic study. *Journal of Phonetics* 8. 343–352.
- Nakai, Satsuki, Sari Kunnari, Alice Turk, Kari Suomi, & Riikka Ylitalo. 2009. Utterance-final lengthening and quantity in Northern Finnish. *Journal of Phonetics* 37(1). 29–45.
- Nasr, Raja T. 1960. Phonemic length in Lebanese Arabic. *Phonetica* 5. 209–211.
- Nasr, Raja T. 1966. *Colloquial Arabic: An oral approach*. Beirut: Librairie du Liban.
- Ohala, John J. 1983. The origin of sound patterns in vocal tract constraints. In Peter F. MacNeilage (ed.), *The production of speech*, 189–216. New York: Springer-Verlag.
- Payne, Elinor. 2005. Phonetic variation in Italian consonant gemination. *Journal of the International Phonetic Association* 35(2). 153–189.
- Payne, Elinor. 2006. Non-durational indices of gemination in Italian. *Journal of the International Phonetic Association* 36(1). 83–95.
- Pind, Jörgen. 1999. Speech segment durations and quantity in Icelandic. *Journal of the Acoustic Society of America* 106(2). 1045–1053.
- Podesva, Robert. 2000. Constraints on geminates in Buginese and Selayarese. *Proceedings of the West Coast Conference on Formal Linguistics* 19. 343–356.
- Ridouane, Rachid. 2007. Gemination in Tashlhiyt Berber: an acoustic and articulatory study. *Journal of the International Phonetic Association* 37(2). 119–142.
- Ridouane, Rachid. 2010. Geminates at the junction of phonetics and phonology. In Cecile Fougeron & Mariapaola D'Imperio (eds.), *Papers in Laboratory Phonology 10: Variation, detail and representation*. Berlin: Mouton de Gruyter.

- Ringen, Catherine O., & Robert M. Vago. 2011. Geminate: heavy or long? In Charles E. Cairns & Eric Raimy (eds.), *Handbook of the syllable*, 155–170. Boston and Leiden: Brill.
- Selkirk, Elizabeth. 1990. A two-root theory of length. In Elaine Dunlap & Jaye Padgett (eds.), *UMOP 14: Papers in Phonology*, 123–171. Amherst: GLSA.
- Suomi, Kari, & Riikka Ylitalo. 2004. On durational correlates of stress in Finnish. *Journal of Phonetics* 32(1). 35–63.
- Thurgood, Graham. 1993. Geminate: a cross-linguistic examination. In Joel A. Nevis, Gerald McMenamin, & Graham Thurgood (eds.), *Papers in Honor of Frederick H. Bengelman on the occasion of the 25th anniversary of the Department of Linguistics*, 129–139. Fresno, CA: Dept. of Linguistics, CSU Fresno.
- Tranel, Bernard. 1991. CVC light syllables, geminates and Moraic Theory. *Phonology* 8. 291–302.
- Tserdanelis, Giorgos, & Amalia Arvaniti. 2001. The acoustic characteristics of geminate consonants in Cypriot Greek. *Proceedings of the Fourth International Conference on Greek Linguistics*, 29–36. Thessaloniki: University Studio Press.
- Turk, Alice, Satsuki Nakai, & Mariko Sugahara. 2006. Acoustic segment durations in prosodic research. In Stefan Sudhoff, Denisa Lenertova, Roland Meyer, Sandra Pappert, Petra Augurzky, Ina Mleinek, Nicole Richter, & Johannes Schlieber (eds), *Language context and cognition: methods in empirical prosody research*, 1–28. Berlin and New York: Walter de Gruyter.
- Watson, Janet. 2007. Syllabification patterns in Arabic dialects: Long segments and mora sharing. *Phonology* 24(2). 335–356.