論文

Evidence of Gemination in Persian
(Phonetic and phonological study of lexical and post-lexical geminates)

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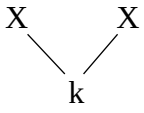
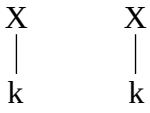
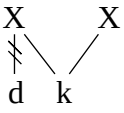
Abstract

The purpose of this study is to examine the phonetic interpretation of geminate contrast and the articulatory differences between the lexical and post-lexical geminates in Persian. In terms of two geminate types, the findings indicated that word-boundary geminates display the same temporal values as lexical geminates, however, unlike lexical geminate consonants, the phonetic implementation of adjacent identical consonants in word-boundary geminates are not allocated the feature [+tense]. Such phonologically difference affected the vowels preceding the two geminate types. Results from analyzing the qualitatively short and long vowels preceding the word-boundary geminates showed separate distributions for consonant sequences affected by different vowel types in which the tenseness of the vowel /ɑ/ and the duration of consonant sequences would result in considerable interaction. Contrary to RMS amplitude, formant frequencies as a robust secondary cue, could contribute to the perception of the vowel and consonant discrimination in two types of geminates in Persian. These results demonstrate that temporal compensation is maintained with the interaction between the preceding vowels and consonants in two geminate types. Duration as a primary correlate would be enhanced by Formant Frequency values as an additional acoustic correlate and increases the perceptual distance between the phonemic categories.

1. Introduction

This paper presents findings on the articulatory conditioning of lexical and post lexical geminate consonants in Standard Contemporary Persian. The phonetic and phonological distinctions between the different types of geminates have been studied in many of the world's languages, as well as studying the differences between singleton and geminate consonants. Phonological research describes two different types of geminates with differing structures. Lexical geminates are phonemic and represent as single melodic units associated with two timing slots (Leben 1980), whereas post lexical geminates are formed by concatenation of two identical consonants across a word boundary or by total assimilation of a segment which takes the identity of the adjacent segment at a word internal morpheme boundary (McCarthy 1986; Hayes 1986; Lahiri and Hankamer 1988; Ridouane 2010; Oh and Redford 2011). The representations of singletons, lexical geminates, geminates created by concatenation of two identical stops across a morpheme boundary and a geminate derived by total assimilation are illustrated in the Table 1.

Table1. The representations of singleton and three types of geminate consonants

singleton	Lexical geminate	Concatenated geminate	Assimilated geminate
			

To some extent, morphological boundaries impact the phonetic manifestation of geminates. Within phonetic implementation, lexical geminates are phonetically long segments which contrast with their singleton counterparts as short segments (Ladefoged and Madieson 1996), whereas the post lexical geminates are not contrastive in length. Some phonetic studies have shown that generally lexical and post lexical geminates are phonetically identical, as in Bengali and Turkish (Lahiri and Hankamer 1988), Lavantine Arabic (Miller 1987), Sardinian (Ladd and Scobbie 2003) and Tashlhiyt Berber (Ridouane 2010). This is because of the phonological representation of geminates which captures the similarity in the number of timing units lexical and post lexical geminates are associated to. Based on this phonological representation, the difference between lexical and post lexical geminates will not be manifested in absolute timing differences at the phonetic level.

1.1. Relative duration

Although absolute duration of a consonant is usually the primary acoustic correlate of geminate contrasts, this indistinguishable cue is always supported by relative duration. Relative duration, often expressed in duration ratios between two or more segments, presents a more reliable criterion for defining the segmental duration in signaling phonemic contrast (Idemaru and Guion 2010). More substantial differences of relative duration manifest themselves in the duration of preceding vowels. Acoustic evidence has been offered suggesting that there is a temporal compensation relationship between geminates and the vowels preceding them (e.g. Italian: Espisito and di Bendetto 1999; Pickett et al. 1999; Arabic: Al-Tamimi 2004; Malayalam: Local and Simpson 1999; English, German, Spanish and French: Delattre's 1971; etc.). Several studies provided evidence that relative duration plays a critical role in distinguishing lexical and post lexical geminates, where the absolute consonant duration is indistinguishable. Oh and Redford (2011), by taking an example from Tashlhiyt Berber (Ridouane 2010), state that the preceding vowel duration differences for lexical and post lexical geminates should have translated into relative duration differences between the two types of geminates, since Ridouane found that there is no difference in absolute consonant duration of lexical and post lexical geminates. Unlike those studies reviewed above which attempted to define the relative duration differences of contrasting categories, Hansen (2004) stated that the C/V ratio is not a clear discriminator between singleton and geminates in Persian as has been observed in Italian and Icelandic. He claimed that this is partly due to the fact that in Persian the vowel preceding the geminate tends to be longer. Regardless of the representation of geminates and many languages in which gemination has been characterized as a phonological manifestation, phonetic implementation of gemination is described as having an extremely limited domain. This study examines the way these abstract phonological representations are reflected in the phonetic details of speech production, and the way they are related to the distinct behavior of the different types of geminates (namely, Ambiguity and Inalterability). We argue that Persian provides an interesting data

set which represents this explanation.

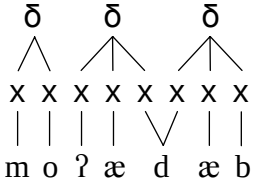
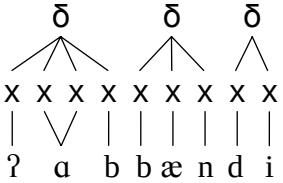
1.2. Current study

Persian has twenty-three consonantal and six vocalic phonemes (University of Victoria Phonetic Database, UPVD 1999). Persian maintains a phonological contrast between geminate and singleton consonants. For example [seri], 'classified' contrasts with [serri], 'mysterious'. Persian has three types of geminates represented as lexical geminates, geminates created by concatenation of two identical stops across a morpheme boundary and a geminate derived by total assimilation. Thurgood (1993) states that cross-linguistically geminates tend to occur in two basic environments; intervocalically and after short stressed vowels. In Persian, lexical geminates can occur only in word medial positions and must be preceded by short vowels. Interesting observations have been made by Iranian researchers regarding geminates: Mahootian (1997) states that for native (non-Arabic) words "the geminates in these words are often, if not usually, reduced." Deyhim (2000) transcribed the pronunciations of 16 speakers of Tehrani Persian and whereas geminated stop consonants in words of Arabic origin are pronounced as geminates by all informants, the geminate stops in native words are pronounced by some of the informants as singletons. For the durational contrasts on geminate stops in Persian, Hansen (2004) provided acoustic evidence suggesting that Persian geminate stops are clearly distinguished from singleton stops in production when speaking rate is taken into account. He examined closure duration, preceding vowel duration, closure to preceding vowel ratio and the utterance duration and showed that the ratio of geminate to singleton closure consistently decreased with increased speaking rate. Hansen (2004) verified that the C/V ratio is not a clear discriminator between geminate and singletons due to the fact that in Persian the vowel preceding the geminate tends to be longer. He considered the syllable duration as a more useful parameter for understanding the distinction between the categories. As Hansen (2004) only analyzed the duration of two stop consonants without considering the different durations of 3 vowels preceding them, it is not clear how the ratio of other consonants to identical preceding vowels duration will play out. As all consonant types in Persian can be geminate, consonants to an identical preceding vowel ratio may need to be specified for managing the data of singletons and geminates. While the findings by Hansen (2004) in Persian geminates are reporting from word-internal geminates' data, one wonders if it is possible to place the effect in more contexts as well as word-boundary geminates.

The present analysis focused on the production of Persian word internal lexical geminates, which are all only found in Arabic loan words, and word-boundary post-lexical geminates to investigate the hypothesis that word internal geminates may differ from those that arise across word boundary (i.e. concatenated geminates). Word internal geminates were compared to phrases with word boundary geminates and to word with singletons to distinguish not only the geminate/singleton contrast, but also to establish whether durational and non-durational properties would distinguish geminates from different boundary types.

Some lexical geminates of Arabic loanwords in Persian are from the Active Participle derived from Arabic verb forms like [moʔallem]. 'teacher'; the infinitive form of the verb like [tafaccor]. 'thought' (Mitchell 1990). In the case of post lexical geminates in Persian our study considered word boundary concatenated geminates. Persian concatenated geminates in word boundaries are represented underlyingly as two timing slots each associated with a single melodic unit (e.g. /ʔɑb+bændi/→ [ʔɑbbændi] (Table 2).

Table 2. Phonetic distribution of word internal and word-boundary geminates in Persian.

Word-internal	Word-boundary
	
[moʔæddæb]	[ʔɑbbændi]

1.2.1. Consonant types

One issue that received relatively less attention in previous literature is the comparison of different manners of geminates in Persian. Other languages that have been studied in this light include Italian (Payne 2005), Cypriot Greek (Arvantini and Tserdanelis 2000), Buginese, Madurese and Toba Batak (Cohn et al. 1999). All consonant phonemes in Persian can be geminate and contrast phonemically with their singleton counterparts. In the present study, ten consonant types [k, b, t, d, s, z, l, r, n, m] were examined in the two geminate type contexts. This subset of consonants was chosen to explore the effect of some certain parameters including place of articulation (bilabial, labiodental, coronal); manner of articulation (stop, fricative, nasal, lateral); and, for the stops, phonological voicing (voiced vs. voiceless), to keep the dataset to a manageable size. The aim was to compare the different manner of consonant geminate types in lexical and post lexical situations and examine whether intrinsic durational properties of consonants condition the way the consonant is geminated and in particular whether these differences result in asymmetries in the duration ratios contrast (see also Payne 2005). Studies have found that the distinctiveness of duration contrasts does depend on consonant manner. For example the predicted relationship between sonority and geminate markedness is supported by Podesva's (2000) survey of 52 languages. It was hypothesized that articulatory factors would result in durational ratios variability and interfere with the production of post lexical geminates.

1.2.2. Vowel types

Preceding vowel duration was also found to be significantly affected by gemination. The interaction between preceding vowel duration and gemination has been reported in many languages (Maddieson 1985). Languages vary in whether geminates shorten or lengthen the preceding vowels. In some languages there are no substantial differences in preceding vowel duration between singleton and geminates; for example Egyptian Arabic (Norlin 1987) and Hungarian (Ham 2001). In Cypriot Greek, there is a slight tendency toward shortening before geminates, but this tendency is not very consistent (Arvantini and Tserdanelis 2000). This shortening is generally explained by syllable structure differences between singletons and geminates: The vowel is longer in an open syllable (V.CV) and shorter in a closed syllable (VC.CV). Ridouane (2010) pointed out that this explanation can probably account for the shortening observed in intervocalic position where the first part of the geminate closes the syllable. The Modern Persian vowel system is generally considered to be a quality-based system in which quantity is not contrastive; e.g. /dir/, 'late' contrasts with /del/, 'heart' and /dur/, 'far' contrasts with /dor/, 'round'. A qualitative distinction (tenseness) categorizes the Persian vowels into two groups: long vowels /ɑ, i, u/ with the feature [+tense],

versus short vowels /æ, e, o/ with the feature [-tense] (Rouhani Rahbar 2009). According to several studies on Persian vowel systems, the length of Persian vowels changes based on the structure they occur in (Samareh 1992; Toosarvandi 2004). Samareh (1977) considered two functionally different groups of Persian vowels with respect to the possible following consonant. The short vowels /æ, e, o/ can occur before all combinations, while the long vowels /ɑ, i, u/ have a very limited occurrence preceding consonant clusters. This context constriction is also the same for geminate consonants in Persian. Qualitatively long vowels cannot occur before geminate consonants. As the preceding vowel duration was found to be significantly affected by geminates, this study carried out a phonetic analysis of two qualitatively short /æ/ and long /ɑ/ Persian vowels as the preceding vowels of lexical and post lexical geminates to investigate whether they have the same behavior as seen in other languages in which vowels are significantly shorter before lexical geminates than concatenated word boundary geminates (Tashlhiyt Berber; Ridouane 2010). It is hypothesized that temporal and non-temporal parameters significantly affected by gemination and word boundary concatenated geminates in Persian may shorten the long vowels preceding them, contrary to some investigations in other languages. This different behavior is due to the special characteristics of the Persian vowel system and their manifestations in different contexts, that is, qualitatively long vowels could occur before concatenated geminates contrary to lexical geminates.

1.3. Aims of the present study

This study seeks to identify the two types of geminates across different boundaries, namely, word-internal (lexical) and word-boundary (concatenated) geminates in Persian and provide a more complete picture of the articulatory conditioning of geminate consonant duration and contrast. In particular, it seeks to establish how far temporal properties like consonant types and local ratios such as consonant/vowel preceding duration ratio shape variability in gemination types and undermine the contrast between the two types. A further aim is to explore whether non-durational properties also distinguish lexical geminates from post lexical, as possibly evident from RMS amplitude during the release of consonants and formant analysis of the preceding vowel's structure. The current study also focuses on the influential role of relational timing of consonant to preceding vowel duration to accurately classify lexical and post lexical geminate productions. We predict that there is more stability in higher-order acoustic properties, namely the relative duration of consonant to vowel duration, than the absolute duration of the consonants. To test this, we conducted an acoustic study to examine absolute consonant duration and various local ratios as well as consonant to preceding vowel duration ratios (C:V1). The categorization power of duration ratios versus absolute consonant duration was also considered. Finally we conclude with a brief discussion of some non-durational analyses as well as RMS amplitude, phonation differences in the consonants and the quality and quantity effects on the preceding vowel by analyzing the Formants.

2. Methods

2.1. Participants

Eight native speakers of Persian (4 male, 4 female) who reported normal hearing, participated. All were native speakers of Persian and were born of Persian speaking parents. The mean age ±SD of the participants was 31.2 ±4.7 ranging from 25 to 40 years old. None of them reported any speech disorder.

2.2. Stimuli

The stimuli were 32 Persian and Arabic loan words, presented in Tables 3 and 4. All test words are stressed on the last syllable, because stress falls on the last syllable of Persian nouns. Three factors, namely, absolute consonant durations, the duration of the preceding vowel and the local ratio of consonant to preceding vowel duration were examined in lexical and word-boundary concatenated geminate contexts and compared with their singleton counterparts. To measure the duration, we followed the standard criteria of segmentation. Following Arvaniti and Tserdanelis (2000) and Ridouane (2010), separate measurements were taken for closure duration and release duration values for voiceless stops, VOT, and for voiced stops, to highlight the difference in gemination effect and the two geminate types for these two series of stops. For analyzing the target consonants in lexical geminates, the trisyllabic Arabic loanwords of the form $CVC_1V_1C_2C_2VC$ ([mofæʔʔæl]) were chosen in which C_2 cover the ten consonant types [k, b, t, d, s, z, l, r, n, m] and the last syllables, C_2VC, were stressed. The tokens of concatenated word boundary geminates were limited to four stop consonants [b, d, c, t] and the test words were disyllabic of the form $CV_1C_1.C_1VC$. The last syllable C_1VC of items were all stressed similar to the first set of items. In constructing the test stimuli to evaluate the gemination type differences, lexical geminates which contained only the same four stop consonants of [b, d, c, t] were selected. Word internal and word boundary geminates were compared also with their singleton counterparts to provide a more complete picture of the articulatory conditioning of geminate types compared to singletons. To this aim, the singleton word test counterparts for lexical geminates were selected from disyllabic words of the form $C_1V_1C_2VC$. The syllables C_2VC of items were all stressed. Regarding the comparison between word-boundary geminates and their singleton counterparts, the disyllabic words of the form $CV_1C_1.C_2VC$ were chosen. The syllables C_2VC of items were all stressed. To test the vowel duration, the preceding vowel of V_1 in the lexical words of the form $CVC_1V_1C_2C_2VC$ and also their singleton counterparts of the form $C_1V_1C_2VC$ covered the low front /æ/. Although it may have been ideal to vary the vowel context of the preceding position, only /æ-/ is used for the vowel context in order to obtain a manageable number of test words. Two different vowel contexts were chosen for word boundary geminates of the form $CV_1C_1.C_1VC$ in which they differed in vowel preceding of V_1 namely, low front /æ/ versus low back /ɑ/ (short vs. long vowel). Regarding the comparison between word-boundary geminates and their singleton counterparts, the disyllabic words of the form $CV_1C_1.C_2VC$ with the vowel context of /Cα C_1/ and /CæC$_1$/ were chosen. It is worth noting that V_1 of all test words which preceded singleton and geminate consonants were unstressed.

Mapping the difference between the two geminate types, and the effect of two vowel types on word-boundary geminates, additional measurements, namely non-temporal indices were obtained. It is worth noting that the longer duration of the closure for geminates may lead to higher amplitude upon a release of a long plosive (Hankamer et al. 1989). RMS amplitude of the target consonants in word-internal and word-boundary geminates was measured in the VOT and release duration of stop consonants. Differences between the two geminate types are not restricted only to duration. To test the consonantal resonance and vowel qualities in word-boundary and lexical geminates, F1 and F2 of the two qualitatively short and long vowels preceding the word-boundary geminate consonants and the singleton counterparts, F1 and F2 of the target consonants in word-boundary, F1 and F2 of the vowel preceding the lexical geminates and F1 and F2 of the target

lexical geminate consonants were measured at mid-point. Constructing the manageable data set, lexical and word-boundary geminates containing the stop consonants were selected for analyzing the formants. The materials collected for analyzing temporal parameters was also subject to the RMS amplitude and Formant analysis. The subset of non-temporal parameters consist of lexical and word-boundary geminate consonants and the vowels preceding them. The 8 subjects were asked to produce each token 3 times, yielding 768 tokens in total.

Table 3. List of stimuli with the target singleton/lexical geminates

1. Word internal lexical geminates			2. Singleton counterparts		
Form	Gloss		Form	Gloss	
mo?æddæb	polite	موَدّب	?ædæb	politeness	ادب
mo?ænnæs	female	موَنّث	fænær	coil	فنر
mo?æmmæm	popularized	معمّم	sæmær	fruit	ثمر
mocællæf	required	مکلّف	?ælæf	grass	علف
moræccæb	compound	مرکّب	ræcæb	deceive	رکب
mo?ættær	aromatic	معطّر	xætær	risk	خطر
mocærræm	holy	مکرّم	cæræm	magnificence	کرم
moræbbæ?	square	مربّع	?æbæd	eternity	ابد
moræssæ?	carbuncled	مرصّع	?æsær	effect	اثر
mo?æzzæb	tortured	معذّب	?æzæb	torture	عذب

Table 4. List of stimuli with the target singleton/word-boundary concatenated geminates

3. Concatenated word boundary geminates			4. Singleton counterparts		
Form	Gloss		Form	Gloss	
ʔabbɑz	diver	آب باز	ʔɑbdɑr	juicy	آب دار
tæbbor	refrigerant	تب بر	tæbdɑr	feverish	تب دار
pɑkkon	eraser	پاک کن	pɑcʃu	a trade name for "detergent"	پاک شو
hækkɑr	sculptor	حک کار	ʃædɑr	skeptic	شک دار
jɑddɑʃt	note	یادداشت	jɑdgɑr	souvenir	یادگار
bæddel	pessimist	بدل	bædcɑr	evil	بدکار

2.3. Procedure

The 32 words shown in Table 3 and 4 were imbedded in similar carrier phrase used in Hansen (2004):

Ali goft ke ____ naboud.

Ali said that ____not-was.

Ali said that (the)_____wasn't there.

Participants read the sentences from 3 randomized lists of 32 words, yielding a total of 768 words collected for analysis. Each speaker was given several minutes to look over the stimuli before recording began. Unfamiliar words were defined and produced by the experimenter for the speaker. All recordings were made in an isolated situation using a Shure SM10A Microphone and a Zoom H4 digital recorder. The recorded utterances were saved in digital format for later analysis.

2.4. Measurements

The spoken phrases were displayed in Praat (Boersma and Weenik 2007). Measurement criteria were established after visual inspection of both the

spectrogram and the waveform. Acoustic duration of the pre-consonant vowel and consonant duration for fricative and nasals and closure duration for stops were considered as temporal parameters. Segmentation procedures described below followed those outlined in prior studies (Lahiri and Hankamer 1988; Hankamer et al. 1989; Payne 2005). The duration of stop consonants which is defined as the closure duration and the VOT, was measured from the offset of the preceding vowel from the last complete periodic cycle in the waveform to the onset of the first complete periodic cycle in the waveform of the following vowel. Similar to previous studies (Cohn et al. 1999; Payne 2005; Idemaru and Guion 2008), VOT was included as part of the consonant duration which enabled a compatible measurement for the durations of voiced and voiceless stops. Fricative consonants was taken to be the period of time elapsed between two points of the left edge of frication noise to the onset of the following vowel, defined as the first complete periodic cycle. The sonorant consonants were measured from the sudden reduction in amplitude and lowering of formants to the onset of the following vowel. The vowel duration was measured from the onset of the first complete periodic cycle to the offset of the last complete periodic cycle in the waveform with reference to the visible energy of the second formant (F2) of a time-locked spectrogram. Advanced statistical methods were used in order to consider the main effects of all factors as well as factor by factor interactions. The General linear Model (GLM) univariate procedures which provide analysis of variance were considered to be an appropriate model in this study. Two separate two-way univariate ANOVAs were utilized to assess differences of consonant types and preceding vowel durations between lexical geminates and their singleton counterparts. Separate two-way ANOVAs were conducted for the analysis of the duration of word-boundary geminates and the matched singletons and the vowels preceding them. The differences between the two kinds of geminates regarding the duration of their preceding vowels and the consonant durations were also analyzed by using a two-way ANOVA. Separate two-way ANOVAs were run on measurements for non-temporal parameters, namely RMS amplitude and formant analysis for each condition. An alpha level of 0.05 was set as the level of significance. SPSS 20.0 statistical software was used for all of the descriptive and analytic statistics.

3. Results

3.1. Singleton versus lexical geminates

The first part of analysis investigated duration differences of lexical geminates and their singleton counterparts in terms of absolute and relative duration of the target consonants. Consonant duration is supple according to consonant types and geminate types. Table 5 reflects the mean durations of singleton and lexical geminate tokens across consonant types vary from 63.87 ms (SD = 2.034) to 149.143 ms (SD = 9.325) for singletons, and from 162.541ms (SD = 7.601) to 246.351ms (SD = 13.602) for geminates. Figure 1 shows mean duration across consonant types. As might be expected, voiceless consonants are longer than their voiced counterparts. Measurements show the longer average of 1.1 times for geminates and 1.3 times for singletons. As a preliminary screening, a 2 x 10 (Geminacy x Consonant Type) GLM univariate analysis of variance (ANOVA) was run. As predicted, the difference between consonant types was highly significant [$F(9, 460) = 1467.338$, $p < 0.000$]. The same test revealed that differences between Geminacy, namely singleton versus lexical geminate consonants were significant [$F(1,460) = 41504.79$, $p < 0.000$]. There were also a significant interaction between consonant type and Geminacy [$F(9, 460) = 248.372$, $p < 0.000$]. The factor consonant type tested the effect of 10 consonant

types regarding the manner of articulation and found that the geminate counterparts of intrinsically short singletons are relatively short; it also applies to long consonants. The longest durations were obtained for voiceless stop /k/ for which the mean durations of 149.143 ms and 246.351 ms were measured for singleton and geminate respectively. The shortest duration were measured for the lateral /l/ with the durations of 63.87ms for singleton and 162.541 ms for the matched geminates. The factor quantity tested the effect of singleton and geminate consonant on duration. Along with many other study results on various languages (Esposito and Di Benedetto 1999; Lahiri and Hankamer 1988; Redouane 2010) consonant durations show the most robust correlations that distinguishes singletons from geminates in Persian.

Table 5: Mean duration (ms) and Standard Deviation of the target consonants in singleton/lexical geminates (N=480)

	t	k	b	d	s	z	m	n	l	r
singleton	144.168 (10.561)	149.143 (9.325)	115.321 (8.361)	96.327 (4.012)	134.13 (11.025)	123.357 (12.305)	85.915 (9.203)	71.661 (3.201)	63.872 (2.034)	65.789 (4.102)
geminate	244.961 (11.817)	246.351 (13.602)	221.584 (20.301)	198.698 (8.604)	194.552 (5.302)	178.699 (10.551)	205.694 (14.506)	203.669 (8.642)	162.541 (7.601)	165.989 (9.632)

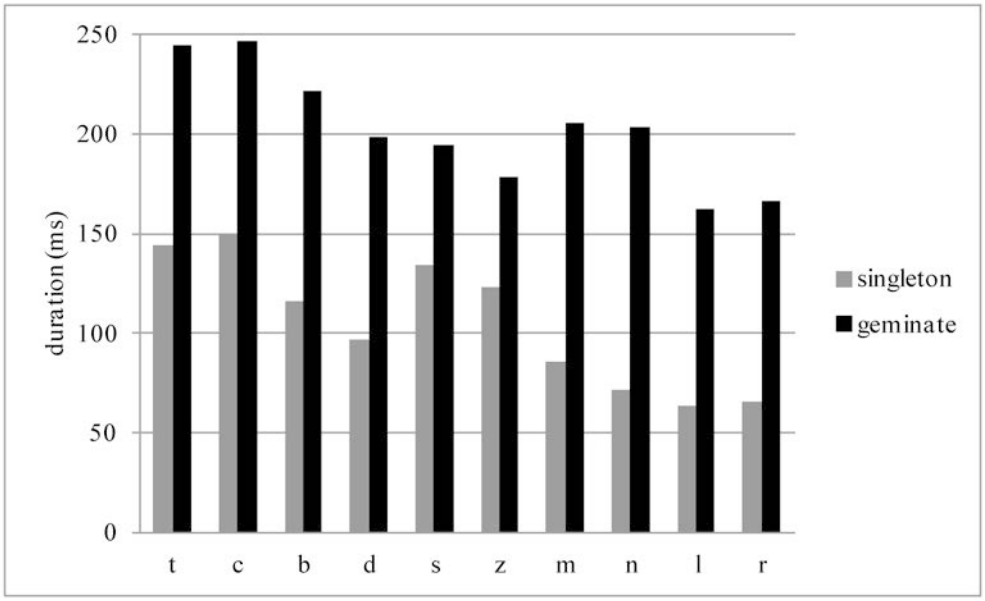


Figure 1: Mean duration (ms) of the singleton and lexical geminate consonant types

Table 6 sums up the effect of gemination on the release duration of voiced and voiceless stops as well as their closure duration, considered as the temporal parameters. The table shows the mean duration (ms) and standard deviation of the tokens across speakers, repetitions and consonant types. Release duration values are presented separately to highlight the differences in gemination effect for voiced and voiceless stops. As Figure 2 illustrates the durational differences, all temporal parameters are significantly affected by gemination, except the VOT duration for voiceless stops which had the same duration for singleton and geminates. The GLM univariate analysis of variance indicated that closure duration of stops were highly affected by gemination [$F(1,184) = 33587.19$, $p < 0.000$]. The significant difference between consonant types was also predicted [$F(3,184) = 687.658$, $p < 0.000$]. There was no significant interaction between consonant types and the geminacy [F(3,

184) = 5.903, p = 0.01]. Significant differences in the release duration according to the presence or absence of gemination were confirmed by one-way ANOVA only for voiced stops [F(1,92) = 464.76, p <0.000]; while the same test revealed that there are no significant differences between singleton and geminate voiceless stops in case of VOT [F(1,92) = 0.9838, p = 0.3238].

Table 6: Mean duration (ms) and Standard Deviation of 4 stop consonants across the temporal parameters (Cld = Closure duration, Rld = Release duration of voiced stops, VOT = VOT of voiceless stops) (N=192).

	t Cld	t VOT	k Cld	k VOT	b Cld	b Rld	d Cld	d Rld
singleton	65.766 (8.521)	78.402 (9.565)	74.911 (8.022)	74.232 (6.325)	100.213 (13.057)	15.112 (2.042)	79.936 (4.407)	16.391 (2.385)
geminate	167.409 (10.817)	77.552 (8.264)	173.919 (11.254)	72.432 (5.287)	197.247 (11.452)	24.335 (3.898)	177.462 (7.567)	21.236 (4.603)

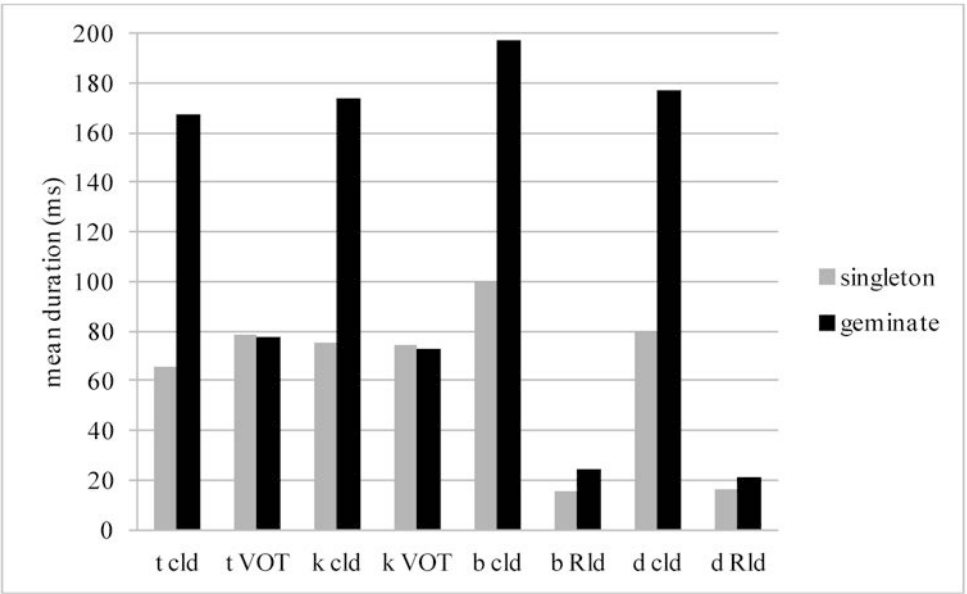


Figure 2: Effect of gemination on the temporal parameters

As the Table 7 and Figure 3 illustrate, preceding vowel duration /æ/, is affected by gemination. The GLM univariate test indicated that there was a significant difference of vowel duration due to gemination [F(1,460) = 1493.75, P <0.000]. Contrary to Hansen (2004) who claimed that in Persian, the preceding vowel is lengthened before geminates, our data revealed that vowels tended to be shorter before geminates but the effect was not consistent across consonant types. The same test revealed that the effect of consonant types was also significant [F(9,460) = 53.112, p <0.000]. The interaction between the consonant types and gemination contrast was also significant [F(9,460) = 20.604, P <0.000]. Despite this, the duration differences between the vowels preceding the singleton and geminate consonants were on average 14.294 ms and only the duration difference for /k/ (24.659 ms) and /d/ (33.079 ms) were longer than the average. Considering the maximum (107.161 ms) and minimum (57.882 ms) average difference between the duration of singleton and geminate consonants mentioned in Table 5 and Figure 1, enhance the possibility that the effect of gemination on relative duration ratio to be considered as a more robust perceptual cue than the duration of the absolute preceding vowel duration alone.

Table 7: Mean duration (ms) and Standard Deviation of the vowels preceding the target singleton/lexical geminate consonants (N=480)

	t	k	b	d	s	z	m	n	l	r
singleton	116.168 (8.803)	137.243 (10.829)	126.547 (16.252)	136.333 (8.022)	118.456 (20.336)	125.255 (9.668)	113.771 (14.597)	116.939 (16.332)	124.438 (20.124)	132.466 (21.005)
geminate	105.888 (9.355)	112.584 (11.692)	116.351 (4.394)	103.254 (9.632)	106.332 (12.374)	108.522 (7.548)	99.2102 (3.205)	99.251 (3.602)	108.471 (9.302)	115.441 (8.201)

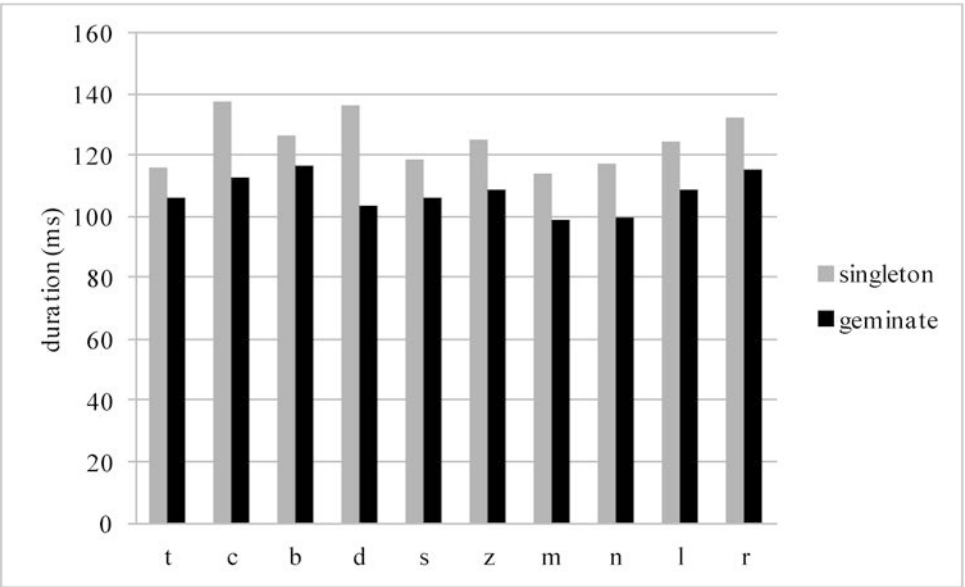


Figure 2: Mean Duration (ms) of the vowels preceding the target consonants

The consonant to vowel preceding ratio of each consonant type across the function of lexical geminates and the matched singletons are shown in Table 8 and Figure 3. The results revealed that gemination contrast was highly affected the ratio of consonants to their vowels preceding them [$F(1,140) = 724.572$, $p < 0.000$]. The consonant type articulation also affected the consonant to vowel preceding ratio [$F(9,140) = 22.097$ $p < 0.000$].

Table 8: Vowels preceding/Consonant Duration Ratios as a function of singleton/lexical geminate consonants (N=160)

C/V1	t	k	b	d	s	z	m	n	l	r
singleton	1.241	1.086	0.911	0.706	1.132	0.984	0.755	0.612	0.513	0.496
geminate	2.313	2.188	1.904	1.924	1.829	1.646	2.073	2.052	1.498	1.437

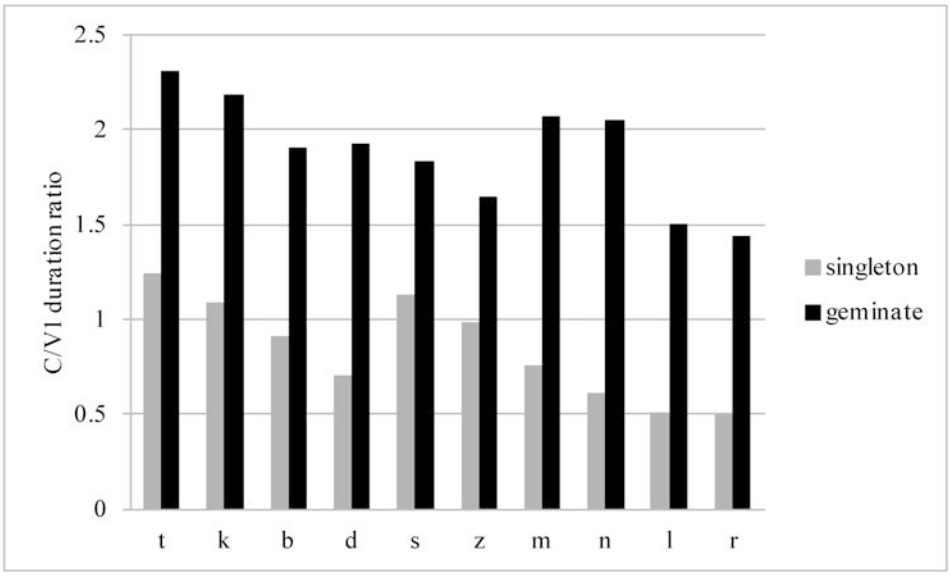


Figure 3: Vowels preceding/Consonant Duration Ratios as a function of singleton/lexical geminate consonants

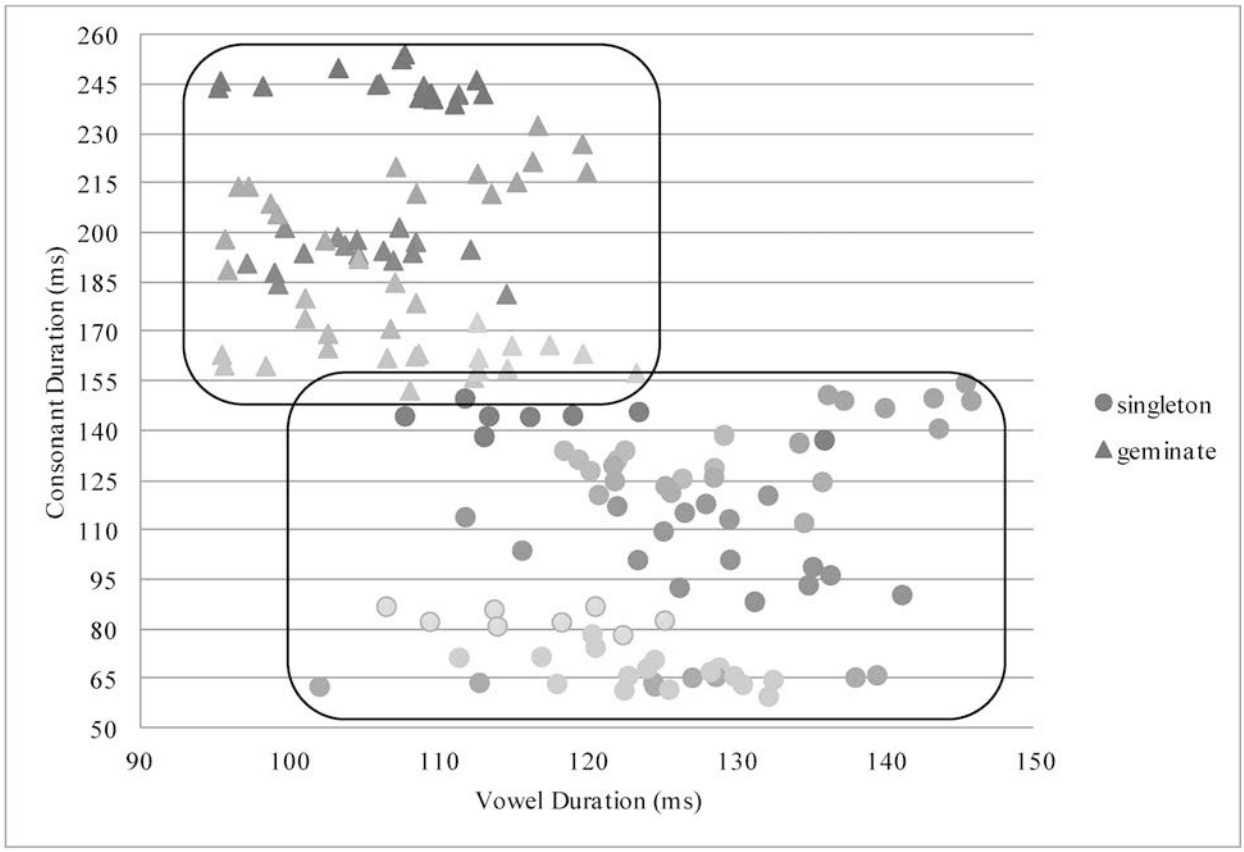


Figure 4: Scatter plot of consonant duration (ms) vs. preceding vowel duration (ms). The circles are singletons and the triangles are geminates, colored in case of different consonant types (N=160).

The effect of consonant to preceding vowel ratio (C/V1) is clearly indicated in the scatter plot in Figure 4. As predicted, vowels preceding singleton consonants were longer than the geminate consonants which shorten the vowels preceding them. Thus, the data presented in the plot shows that the difference between lexical geminates and the matched singletons can be discriminated with almost all of the C/V1 ratios in Persian.

3.2. Lexical versus word-boundary concatenated geminates

The phonetic characteristics of differences between geminate types in Persian have not been significantly investigated as in other languages. Table 9 and Figure 5 show the duration of stop consonant properties affected by gemination in lexical and word-boundary geminates; namely, closure duration (Cld), VOT and release duration of the four voiceless and voiced stops /b, k, t, d/. Geminate consonants were identical for both types of geminates to control the comparison between them. Results show that the trend is still longer for the closure duration of word-boundary geminates than the lexical ones, with the difference of the average of 5 ms, but the univariate analysis of variance ANOVA revealed that there were no high significant differences between them [$F(1,184) = 6.867$, $p = 0.0314$]. Although the effect of consonant types was significant in each geminate type [$F(3,184) = 182.233$, $p < 0.0001$], their interaction showed no significant difference [$F(3,184) = 1.225$, $p = 0.302$]. The effects of geminate type on VOT [$F(1,92) = 0.093$, $p = 0.835$], and release duration [$F(1,92) = 0.789$, $p = 0.376$] were not significant. Thus, in case of the consonant duration, geminates produced the same released duration in two different boundary types. It is possible that the small difference found between the duration of the closure duration may be attributed to the pause inserted by the speakers in word-boundary concatenated geminates.

Table 9: Mean Duration (ms) and Standard Deviation of Consonants in two types of geminates.
(Cld = Closure duration, Rld = Release duration of voiced stops, VOT = VOT of voiceless stops) (N=192)

	t Cld	t VOT	k Cld	k VOT	b Cld	b Rld	d Cld	d Rld
Word-boundary	172.229 (7.854)	78.583 (5.142)	177.418 (8.996)	73.255 (2.175)	205.697 (11.012)	23.634 (1.281)	183.927 (8.692)	20.655 (6.201)
Lexical	167.409 (10.817)	77.552 (7.128)	173.919 (11.254)	72.432 (5.964)	197.247 (11.452)	24.335 (3.162)	177.462 (7.567)	21.236 (2.038)

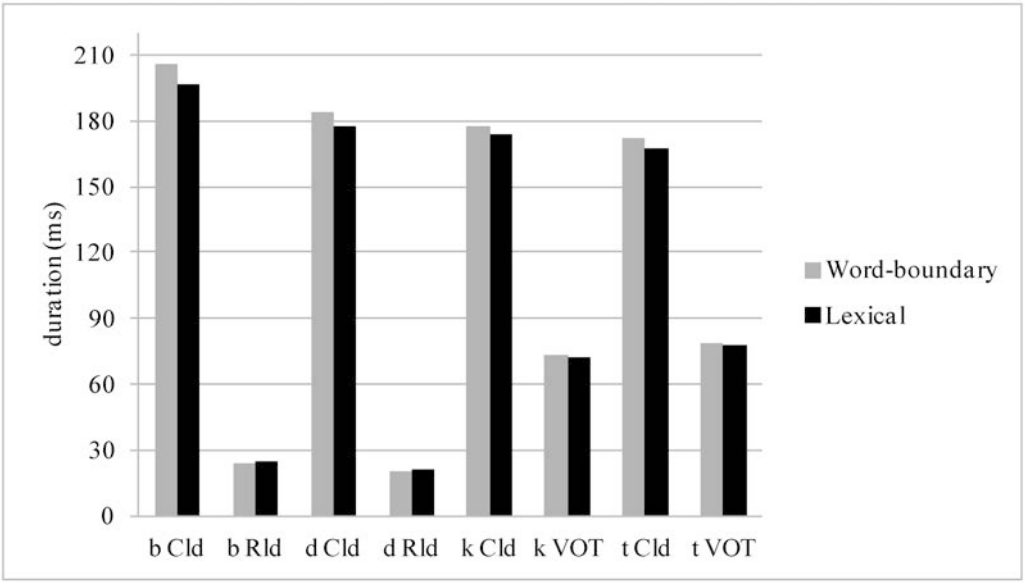


Figure 5: Duration (ms) of the target consonants in the function of word-boundary and lexical geminates

Looking at the results found in case of vowels preceding the two types of geminates, contrary to what was found in Bengali by Lahiri and Hankamer (1988), significant differences were observed in the preceding vowel durations between word-boundary and lexical geminates in Persian [F(1,190) = 28.882, p <0.000]. In order to obtain a thoroughly controlled comparison, the vowels preceding the two geminate types were identical (/æ/). Measurements of the preceding vowel durations displayed that these segments are significantly shorter before lexical than word-boundary geminates; the same results were also obtained by Ridouane (2010) on Tashlhiyt Berber. Results illustrated in Table 10 and Figure 6 indicated that while there was a highly significant difference between the duration values of the vowels preceding the lexical geminates and their matched singletons [F(1,190) = 181.330, p <0.000], there were no high statistical differences between the vowel duration preceding the word-boundary geminate consonants and the singleton counterparts [F(1,190) = 7.636, p = 0.06]. However the analysis of word-boundary geminates revealed the same temporal values as lexical geminates, their effects on the preceding vowels displayed that lexical geminates always affected the duration of the preceding vowels by shortening them while word-boundary geminates did not. It is supposed that the different behavior is due to the fact that word-boundary geminates are represented as two adjacent identical consonants, each associated with one melodic position, which is not sufficient to manifest as a lexical geminate with doubly linked segments.

Table 10: Duration (ms) and Standard Deviation of the vowel preceding the target consonants in the function of word-boundary and lexical geminates and their matched singletons (N=382)

æ	Word-boundary	Lexical
singleton	122.032 (12.958)	129.072 (10.904)
geminate	119.198 (10.225)	109.518 (6.745)

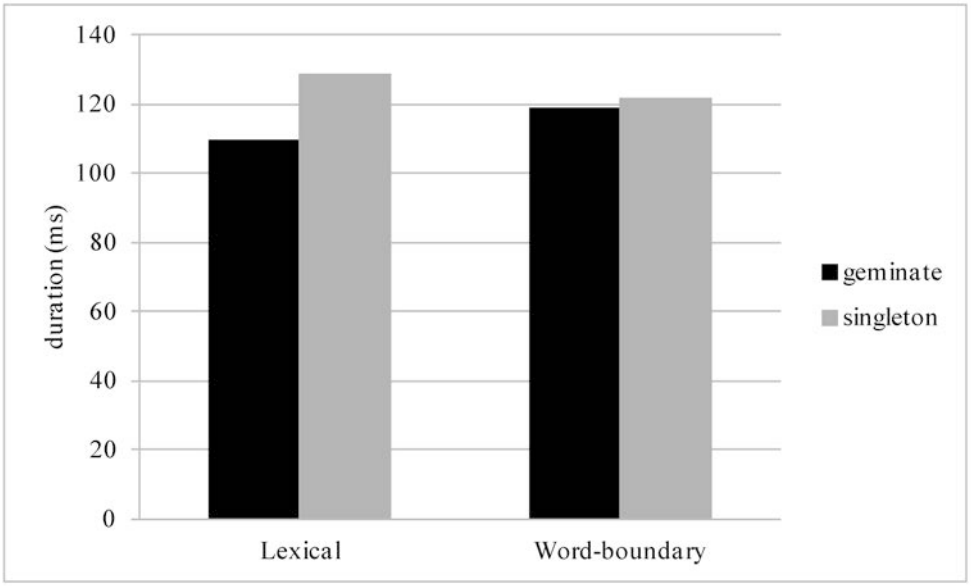


Figure 6: Duration (ms) of the vowel preceding the target consonants in the function of word-boundary and lexical geminates and their matched singletons

The conventional view is that the qualitatively long vowels could not occur before lexical geminates due to the phonotactic constraints in Persian. However, as with the word-boundary geminate articulations, long vowels precede the geminates as well as short vowels. Investigating the results in Table 11 and Figure 7, and based on the results from the GLM univariate analysis of variance, closure durations following the low back vowel /ɑ/ were shorter than when they follow the low front /æ/ [F(1,184) = 48.939, p <0.000] (mean difference = 10.014 ms). It is expected that the vowel duration was also affected by the consonant type differences and the same test revealed the significant differences of vowel differences in each context [F(3,184) = 103.646, p<0.000], but the interaction between the vowel types and consonant types were not significant [F(3,184) = 2.364, p = 0.779]. As predicted there were no significant differences between the VOTs [F(1,92) = 0.735, p = 0.393] and the release durations [F(1,92) = 0.876, p = 0.346] following the two qualitatively short and long vowels.

Table 11: Mean duration (ms) and Standard Deviation of 4 stop consonants in the context of two different vowel types (Cld = Closure duration, Rld = Release duration of voiced stops, VOT = VOT of voiceless stops) (N=192)

	t Cld	t VOT	k Cld	k VOT	b Cld	b Rld	d Cld	d Rld
ɑ	161.255 (9.102)	80.367 (8.321)	168.375 (8.641)	74.059 (6.325)	193.311 (12.302)	24.095 (3.521)	172.894 (9.321)	20.158 (5.336)
æ	172.229 (7.845)	78.083 (4.014)	177.418 (8.901)	73.452 (5.366)	205.083 (10.605)	23.173 (2.005)	183.961 (8.692)	21.153 (3.102)

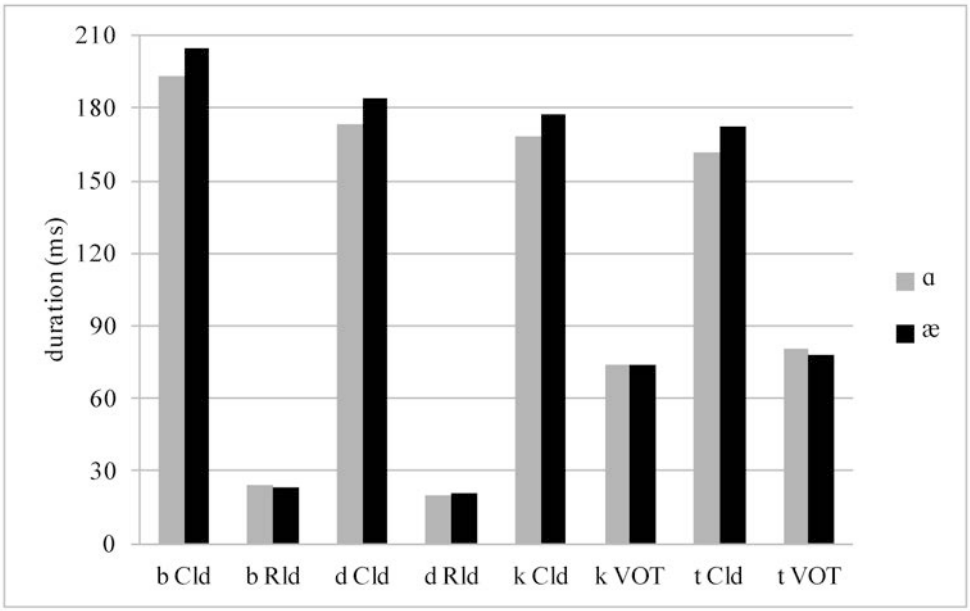


Figure 7: Duration (ms) of the word-boundary concatenated geminates following the qualitatively short and long vowels

Given the relative classification power of the two qualitative vowel types, along with their affection on the consonants following them, the expected results were obtained from the investigated data (Table 12). The acoustic study of the short and long vowel durations preceding the word-boundary geminates and their matched singletons identified almost the same duration differences for /æ/ occurring before singleton and word-boundary geminates [F(1,190) = 7.636, p =

0.06], whereas the significant difference between the duration of low back vowel /ɑ/ preceding singleton and word-boundary geminates [F(1,190) = 474.450, P <0.000] results in the phonotactic patterning in which long vowels associated to two timing slots in the melodic tier tend to phonetically articulate shorter before word-boundary geminates than before their matched singletons. So comparing the results in Figure 7 and Figure 8, as long as the long vowel shortened the closure duration of the consonants following it, the word-boundary geminates also had the same effect on long vowels preceding them.

Table 12: Duration (ms) and Standard Deviation of the qualitatively short and long vowels preceding the word-boundary geminate consonants and their matched singletons (N=384)

	ɑ	æ
singleton	164.048 (5.987)	122.032 (12.958)
geminate	122.729 (8.694)	119.198 (10.225)

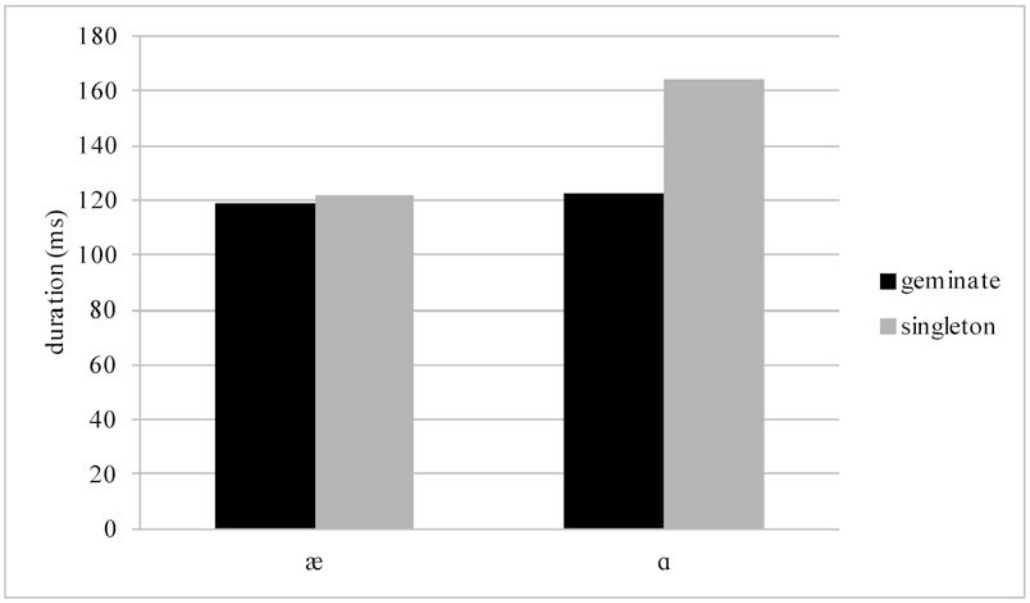


Figure 8: Duration (ms) of the qualitatively short and long vowels preceding the word-boundary geminate consonants and their matched singletons

3.2.1. Non-temporal analysis of lexical/word-boundary geminates

Since the release duration of the target stop consonants could become an important cue to realize a difference between geminate types, the RMS amplitude of the bursts were taken from the VOTs and release durations of the target consonants. The GLM univariate analysis of variance and the results displayed in Figure 9 show the significant difference between the RMS amplitude of the four different consonant types [F(3,56) = 170.571, p <0.000], while a small significant difference was found between whether the geminates were lexical or word-boundary types [F(1,56) = 5.0298, p = 0.028]. The small significant difference of RMS amplitude which occurred in

the two geminate types results in the differences observed in the RMS amplitude of voiceless stops within which the VOT of /kk/ showed a higher RMS amplitude in word-boundary geminate than in lexical [F(1,30) = 12.787, p = 0.001]. The same results were found for /tt/ which displayed the higher RMS amplitude in word-boundary geminates [F(1,30) = 79.423, p <0.0001]. The voiced stops didn't show any significant differences of the RMS amplitude in the different contexts of geminate types. The RMS of /dd/ was not affected by either of the geminate types [F(1,30) = 0.621, p = 0.436]. The geminate /bb/ had an average of 0.255 higher RMS in the lexical context than in the word-boundary type, but this small amount didn't result in a significant difference of RMS between the two geminate types [F(1,30) = 0.942, p = 0.339].

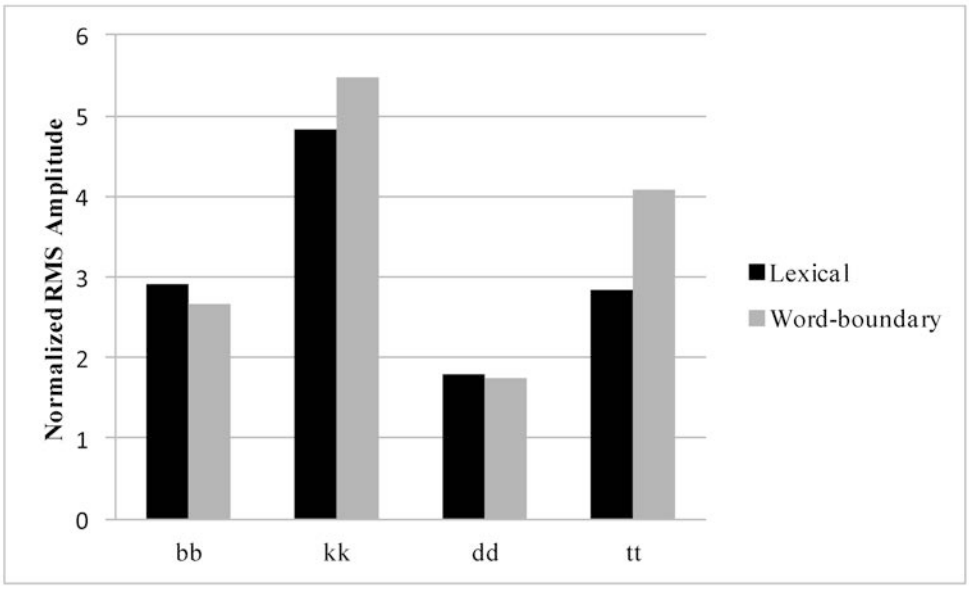


Figure 9: Mean normalized RMS amplitude for voiced and voiceless stop consonants in lexical and word-boundary geminates (N=63)

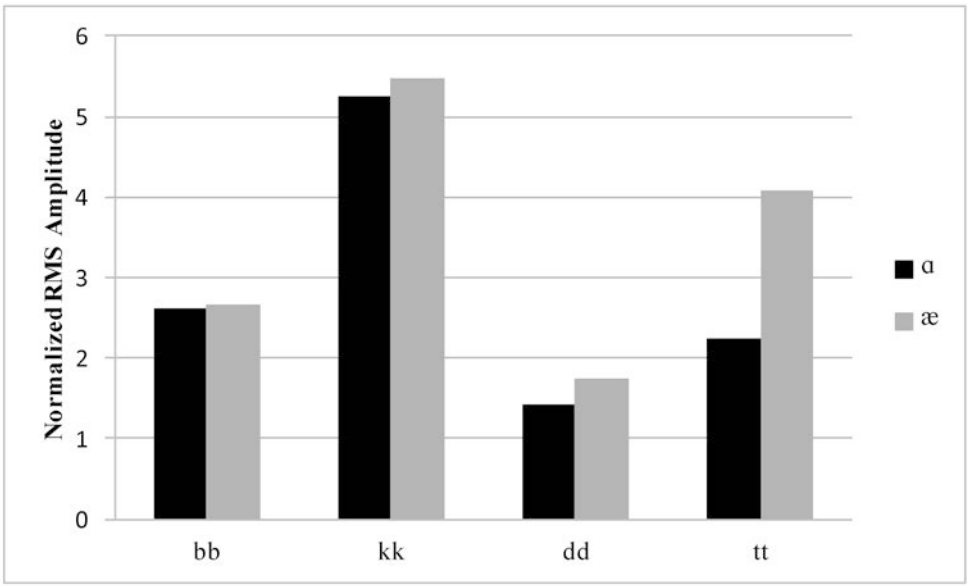


Figure 10: Mean normalized RMS amplitude for voiced and voiceless stop consonants preceding the qualitatively short /æ/ and long /ɑ/ vowels in word-boundary geminates

Figure 10 indicated the results observed for the RMS amplitude of the consonant types following the two different vowel types, namely low front /æ/ and low back /ɑ/ in word-boundary geminates. The RMS amplitude was not affected much by the quality of the vowel types preceding them except for /tt/ [F(1,30) = 51.901, p <0.000] which had a significantly higher RMS amplitude before the short vowel than before the long one. There was also a small significant difference in RMS of /dd/ [F(1,30) = 4.984, p = 0.033], and /kk/ [F(1,30) = 4.129, p = 0.05], but /bb/ [F(1,30) = 2.462, p = 0.127] displayed no significant differences in RMS amplitude. As expected, word-boundary geminates preceding with the long vowel /ɑ/ tend to be produced by lower RMS amplitude compared to their counterparts preceding by short vowels, but the difference is not sufficient enough to serve as additional indices.

We have shown that the phonetic implementation of geminate types and the matched singletons are not restricted to duration alone. In Figure 11, the scatter plot presented clearly F1-F2 space formant plots illustrates the gestural differences between the low back /ɑ/ and low front /æ/ preceding 4 voiced and voiceless stops in word-boundary geminates with their matched singletons. Two separate one-way ANOVA were performed to compare the formant differences of each phonologically short and long vowel preceding word-boundary stop geminates and their matched singletons. Two separate tests were performed to compare the differences of the word boundary stop geminates following the two different vowels and to compare the results with lexical stop geminates. As predicted, results did show a significantly higher F1 [F(1,94) = 2033.199, p <0.000] and F2 [F(1,94) = 7474.427, p <0.000] of the vowel /æ/ than the vowel /ɑ/ before word-boundary geminates. Results also displayed the effect of word-boundary geminates on the vowels preceding them compared with a singleton context, in which F1 of both vowels /æ/ and /ɑ/ was higher than before singletons [F(1,94) = 238.143, p<0.000], [F(1,94) = 365.360, p<0.000]. While F2 of the vowel /ɑ/ preceding geminates was higher (mean difference = 124.970) than in singletons [F(1,94) = 155.279, p<0.000], results did show the lower F2 for /æ/ preceding geminates than (mean difference = -112.805) when it occurred before singletons [F(1,94) = 619.497, p<0.000]. Considering the effectiveness of two different vowel types on the word-boundary stop geminates following them, high statistically significant differences were observed (Figure 12) where F1 [F(1,94) = 210.815, p <0.000] and F2 [F(1,94) = 858.726, p <0.000] were both higher for geminates following /æ/ than when following /ɑ/. The results clearly displayed the effect of the vowels on the word-boundary geminate stops following it, where identical geminate stops were produced with different formants when following different vowels in terms of phonetic shapes.

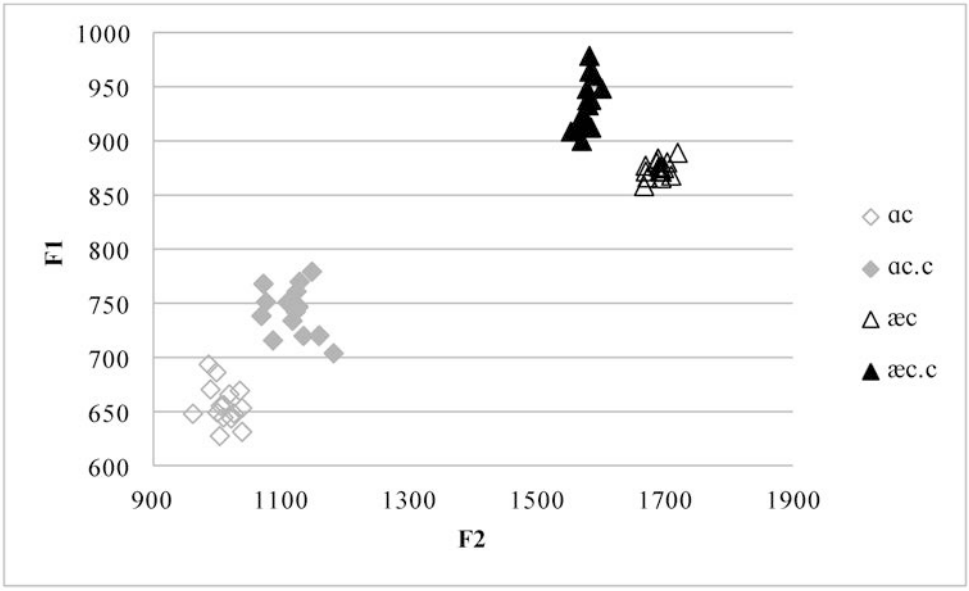


Figure 11: F1-F2 plots of the short /æ/ and long /ɑ/ vowels before singleton and word-boundary geminate stops (where C = /b, d, k, t/)

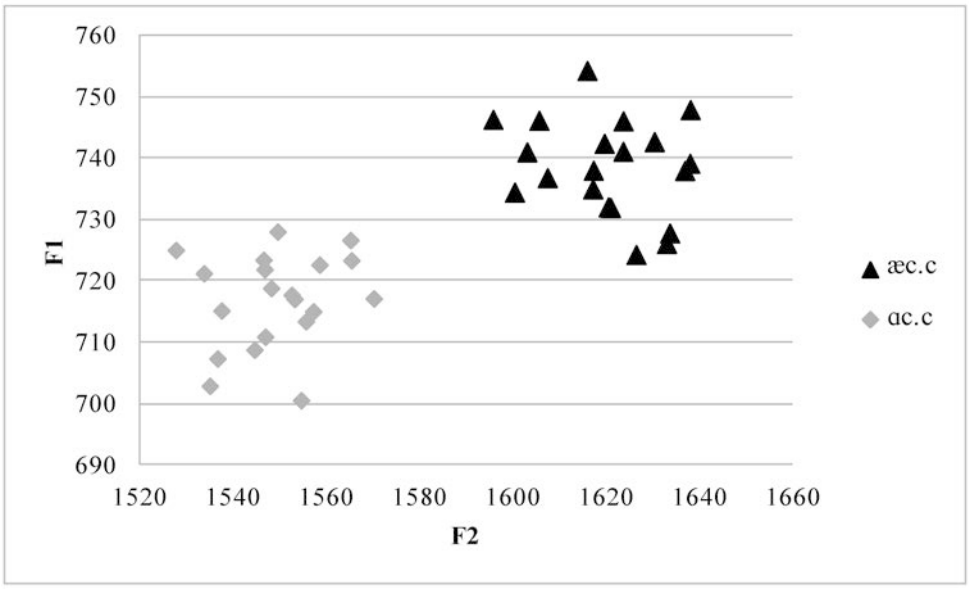


Figure 12: F1-F2 plots of the C.C in word-boundary geminates following two vowel types, (where C.C = /b, d, k, t/)

As Figure 13 shows, F1 values were lower for vowel /æ/ preceding lexical geminates (mean difference= -50.23) compared to when it preceded word-boundary geminates [F(1,94) = 301.416, p <0.000], while F2 is higher (mean difference= 117.704) when preceding lexical geminates [F(1,94) = 1139.694, p <0.000]. Figure 14 illustrates the same results for F1 and F2 of the stop consonants in two geminate types where F1 is higher for word-boundary geminates [F(1,94) = 2212.844, p <0.000] and F2 is higher for lexical geminates [F(1,94) = 2713.453, p <0.000]. As expected the consonant resonance in word-boundary and lexical geminates shown in Figure 14, display the difference of the two types of geminates in which lexical geminates have clearer resonance (more palatalized) than their word-boundary counterparts as they were articulated with higher F2 and lower F1. Considering the effect of geminate types to vowel qualities, the

results indicate that the vowels preceding the lexical geminates are more peripheral in quality than those preceding the word-boundary types; specifically here, the low front vowel /æ/ in æCC (lexical) was produced fronter than that in æC.C (word-boundary).

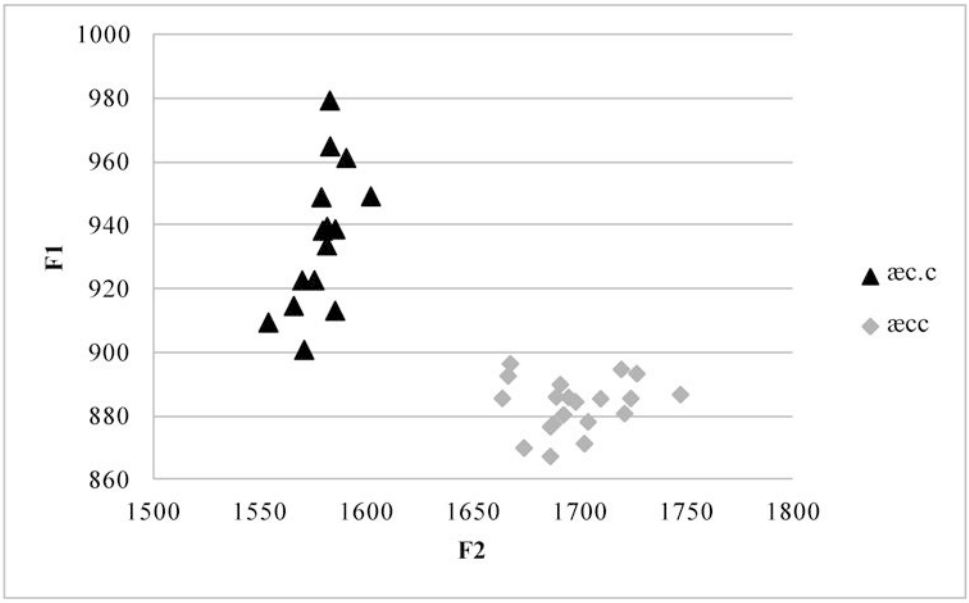


Figure 13: F1-F2 plots of the short vowel /æ/ preceding word-boundary and lexical geminates (where CC = /b, d, k, t/)

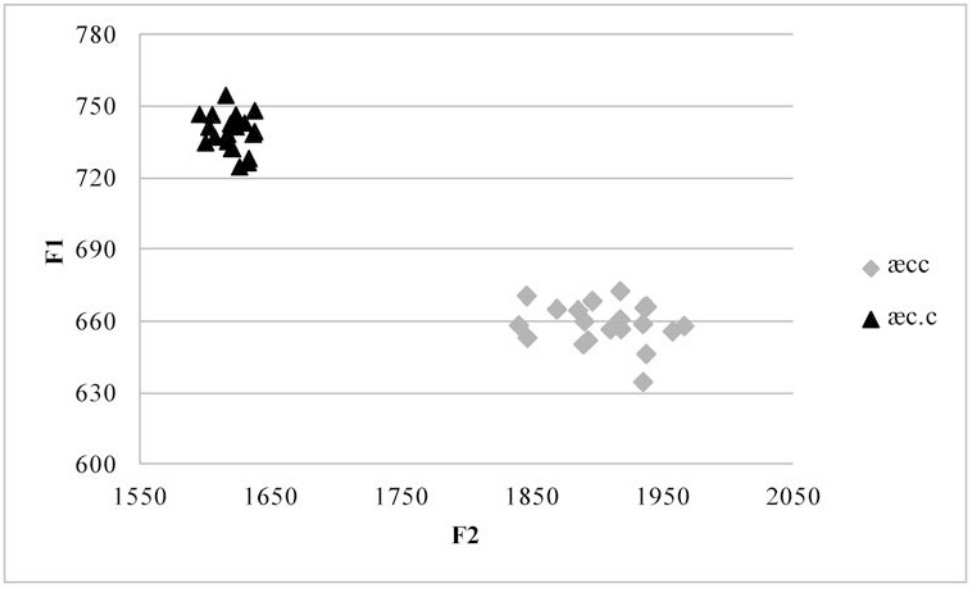


Figure 14: F1-F2 plots of the CC in word-boundary and lexical geminates following /æ/ (where CC = /b, d, k, t/)

4. Discussion

The specific purpose of this study was to assess the difference between two types of geminates, namely, lexical and word-boundary concatenated geminates in Persian. Firstly, analyzing the data from absolute and relational durations of intervocalic consonants and the vowels preceding them has shown that geminate and singleton duration, and the contrast between them, vary according to consonant type. In this case each consonant appears to have an inbuilt relationship

between geminate and singleton duration and the result of the geminate function show the longest duration for /k/ and the shortest one for /l/. Our data demonstrated that in stop consonants the difference between singleton and geminate stops lies only in closure duration used as a robust correlate for gemination contrast. Although there is a significant difference between the release duration of voiced stops in singleton and geminates, the lack of effect of geminacy contrast on VOT in Persian is similar to many other languages including Labanese Arabic (Ham 2001), Bengali (Hankamer et al. 1989) and Berber (Ridouane 2010), whereas Arvantini and Tserdanelis (2000) observed a longer VOT for geminates in Cypriot Greek. Regarding the vowels preceding the target consonants, it should be noted that although preceding vowels are shortened before geminates, the absolute duration differences between vowels preceding singleton and geminates compared to the closure duration (14.294 ms vs. minimum 57.882 ms), didn't display a reliable difference. These findings suggest that durational differences take place in relative rather than absolute duration in that the perception of gemination contrast is mainly achieved through the relative duration for each of the singleton and geminate consonants and the surrounding vowels.

The results from the acoustic study of geminate types suggest that the same sound may be implemented with different lengths in different contexts. The findings show that word-boundary geminates display the same temporal values as lexical geminates, all being produced with the same closure duration, VOT and release duration for stops. Although the absolute duration of lexical and word-boundary geminates were similar and substantially different from their singleton durations, once pre-consonantal vowel length was taken into account, lexical and word-boundary geminates differed and only the vowel /æ/ preceding the lexical geminates were longer than before singletons. Furthermore, the results display the trend of 5 ms longer in the closure duration of word-boundary than lexical geminates which might be interpreted as a pause, which speakers almost always inserted for word-boundaries. This result for Persian geminates is the same as the findings which Oh and Redford (2012) found in word-boundary fake geminates in English in careful speech. They found that in careful speech, speakers also occasionally inserted a pause at a morpheme boundary and between first and second syllable in words with singletons, pause duration in word-boundary geminates was longer than in word-internal geminates or singletons. In contrast to the clear findings through temporal analysis, non-durational boundary cues may not be reliable enough for producing useful generalizations. Contrary to Ridouane (2010) who found that lexical geminates were produced with higher RMS amplitude compared to concatenated geminates in Tashlhiyt Berber, our data investigated in Persian suggested that, due to the lack of the possibility to predict the RMS differences in two geminate types, RMS amplitude doesn't appear to be a good candidate for a consistent secondary cue to discriminate the consonant behavior in the two types of geminates. Unlike the RMS amplitude differences as an insufficient secondary cue to enhance the durational correlate, formant analysis of consonants in the two geminate types and the vowels preceding them may serve as a robust cue and can be found throughout our data. Our findings suggest that lexical stop geminates have clearer resonance than word-boundary geminates. In addition, vowel /æ/ preceding a lexical geminate is relatively more front than the vowel preceding the word-boundary geminates. Thus the lexical geminate effect with lower F1 and higher F2 values on the vowel preceding them and the result is relatively the same formant value for vowels. This result also may be the case for word-boundary stop geminates where the vowel /æ/ before adjacent consonants with higher F1 and lower F2 may be

implemented with the same Formant values. Thus the findings in formant analysis of two geminate types suggest that the effect of geminacy with respect to the more palatalization form is present at the underlying representation of geminate types and therefore also present at the stage of gestural planning. The fact that effects are stronger for lexical geminates providing the lower F1 than word-boundaries indicates that non-durational indices are more robust cues for gemination contrast and that the geminate types are gesturally different.

Although the configuration of a two timing slots representation for word-boundary geminates manifest phonetically identical characteristics as lexical geminates, our results strongly suggest that word-boundary geminates are presented as consonant sequences. The finding that these geminates precede by vowels with the same duration as pre-singletons suggest that the phonetic implementation rule whereby doubly linked segments are assigned the feature [+tense] (Ridouane 2010), will not apply to these two adjacent identical consonants since the structural description of this rule implies that the melodic tier be linked to two timing positions, thus there is no geminate tenseness to shorten the preceding vowel. This opinion is consistent with the finding of the pause speakers inserted in word-boundary geminates. Clearly, both findings argue for the fact that having identical consonant sequences is not sufficient to consider it as a lexical geminate. In terms of this phonological behavior, closure duration of the stops following the qualitatively long vowel /ɑ/, which occur only before word-boundary geminates, were shorter than when they follow the short vowel /æ/. Unlike durational boundaries as a consistent primary correlate, the non-temporal parameter of RMS amplitude was not sufficient enough to serve as a robust secondary cue. Although word-boundary geminates following /ɑ/ have been produced with lower RMS than following /æ/, this difference is not significant enough to enhance the primary correlate. The small difference obtained may be dependent on the tenseness of the vowel /ɑ/ which affects the following consonant sequence to be implemented with lower RMS amplitude.

Interestingly, long vowels which affect the closure duration of the following consonant sequence can also be shortened by the effectiveness of word-boundary geminates, compared to their matched singletons. In contrast, the same durations were interpreted for both the short vowel /æ/ preceding word-boundary geminates and their singleton counterparts. The findings that /ɑ/ behaved differently from /æ/ in the same context could indicate that this different behavior is due to the phonologically active feature in Persian namely, [±tense] as a distinctive feature for the quality contrast, which is strongly accounted for by categorizing the Persian vowels into two groups based on phonotactic patterning such as restrictions on following consonants and versification and raising vowel harmony observed in this language. Considering the categorization of vowels /ɑ, i, u/ vs. /æ, e, o/, all vowels which are considered as long in quantity-based accounts in Persian has the feature [+tense] in the qualitative feature system of vowels. Vowels with the feature [+tense] represent with a melodic tier associated to two timing positions unlike [-tense] vowel which associates to one timing position. Thus the syllable containing a vowel with the feature [+tense] which is already bimoraic, couldn't precede the lexical geminates as a doubly linked segment with the feature [-tense] (Foley 1977; Churma 1988), whereas the allowance of occurring before word-boundary geminates is due to the failure of tenseness in the concatenated segments in a word-boundary (Keyser and Stevens 2006, Ridouane 2010).

The findings that the duration of the vowel /ɑ/ was significantly shorter compared to its singleton counterparts and similar to the duration

of the vowel /æ/ before word-boundary geminates (122.729 ms) are more opaque. It may reflect in the quality of /ɑ/ with the feature [+tense] which has the restrictions for occurring before consonant sequences. Although the word-boundary geminates didn't contain the feature [tense], the virtual similarity of the adjacent consonant duration between word-boundary and lexical geminates, results in shortening the duration of the [+tense] vowel /ɑ/ so that the syllable's weight is maintained. This similarity may be because Persian speakers are sensitive to the relative duration of consonant sequences to the preceding vowels and their perceptions from [+tense] vowels results in shortening them. Another possibility is that the observed surface differences are due to the difference in underlying representation of gestures of word-boundary geminates and vowel types preceding them. It is worth noting that, the underlying gesture for vowels /æ/ and /ɑ/ before singleton consonants is spatially different from when they occur before word-boundary geminates. However our findings suggest that these differences did not display the similar phonetic shape for vowels before word-boundary and lexical geminates. In this interpretation, the vowel /æ/ preceding the word-boundary geminates with high F1 and F2 is implemented more front and higher than the vowel /ɑ/ which reflects the gesture of closer and less front before word-boundary geminates. In other words, considering the effect of the vowel on the following consonant sequences, the word-boundary geminates with the vowel /æ/ preceding them are produced more palatalized like lexical geminates, but with higher F1 value than the lexical ones. This implementation is in contrast with the fact of more front vowels before lexical geminates which shows the different gesture of word-boundary geminates compared to lexical ones. However, consonant sequences following the long vowel /ɑ/ which have been affected by the vowel, are relatively produced with less clearance than they occur before the vowel /æ/. So such a dark resonance (absence of palatalization) pattern of word-boundary geminate implemented after the vowel /ɑ/ would justify the reciprocal effect of the feature [tense] of the vowel and the adjacent consonant duration of word-boundary geminates. To summarize, the patterns of phonetic shape involving the durational and spectral variation in vowels in word-boundary geminates which affect the resonance of the consonant sequences following them, are also a robust secondary cue along with duration and are found in this part of our dataset.

5. Conclusion

The purpose of this study was to examine the phonetic characteristics of lexical and word-boundary geminates considering the effectiveness of two qualitatively short and long vowels preceding them in Persian. We first investigated the phonetic interpretation of geminatation contrast in Persian, with geminate and singleton consonant duration, the effect of consonant types and the interaction of the preceding vowel duration and the local ratio of C/V1. The non-temporal parameters, namely RMS amplitude and the formant frequencies were also examined to explore their effect on distinguishing the different geminate types. The general conclusion of this study is that the primary correlate distinguishing singletons from geminates is duration. But gemination contrast strongly relies on relative rather than the absolute duration of consonants and the vowels preceding them due to the small absolute durational differences. The effect of geminacy on consonant type also was demonstrated by the longest duration for /k/ and the shortest one for /l/. Although in stop consonants the geminatation contrast lies only in closure duration as a robust correlate, VOT and release duration weren't affected by gemination. In terms of two geminate types, the findings show

that word-boundary geminates display the same temporal values as lexical geminates, all being produced with the same closure duration. However these two geminate types differed only in the case that while lexical geminates shortened the vowel /æ/ preceding them word-boundary geminates did not. Furthermore, the results show the trend of 5 ms longer in the closure duration of word-boundary than lexical geminates which might be interpreted as a pause where speakers almost always inserted when speaking carefully. This result with the finding of the pause speakers inserted in word-boundary geminates consistently enough for the fact that the phonetic implementation rule whereby doubly linked segments are assigned the feature [+tense], will not apply for these two adjacent identical consonants. The reciprocal effectiveness of the qualitatively long vowel /ɑ/ and the consonant sequences following it in word-boundary geminates can be represented by the phonologically active feature [+tense] of the vowel /ɑ/. This means that Persian speakers can take advantage of relative duration of consonant sequences of the preceding vowels in their perceptions from [+tense] vowels and shorten them. The study also presented evidence that RMS amplitude, contrary to durational differences as a robust primary correlate, didn't appear to be a good candidate for a consistent secondary cue to discriminate between the two vowel types and consonant behavior in the two types of geminates. In contrast, the distinction between the underlying gesture of consonants in the geminate types and two vowel types in word-boundary geminates displayed that formant frequencies could serve as robust secondary cue to distinguish the geminate types and interpret the manifestation of tense articulation of vowel types in Persian.

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