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Geminates at the junction of phonetics and phonology*

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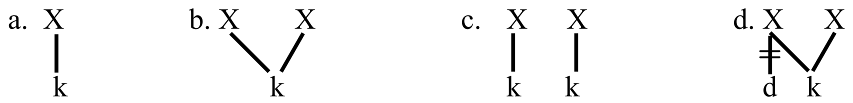
ABSTRACT

Within CV phonology, geminates, including post-lexical ones, are represented as single melodic units associated to two prosodic positions. This study examines the way these autosegmental representations are reflected in the phonetic details of speech production and questions the phonological relevance of these correlates. In particular, it investigates two questions: what are the acoustic and articulatory differences between singletons and lexical geminates; and are there any acoustic differences between the different types of geminates? Tashlhiyt Berber serves as an excellent test case for these issues. This language has contrastive singleton and lexical geminate consonants in all positions. In addition, it presents two types of phonologically derived geminates: concatenated and assimilated ones. Two experimental studies are conducted. Results show that the primary correlate that distinguishes singletons from lexical geminates is duration, even for voiceless stops after pause. This primary correlate is enhanced by additional correlates, which may be crucial to the perception of absolute initial and final geminates. The three types of geminates all show the same temporal characteristics, which supports their receiving the same timing representation, but there are additional phonetic characteristics on which they differ. While assimilated geminates, like underlying ones, are enhanced by additional acoustic attributes, concatenated geminates are not. Implications of these results for the general issue of geminate behaviour are discussed, with particular attention to geminate Ambiguity and geminate Inalterability.

1. Introduction

Geminates, as reported in many languages of the world (Ladefoged and Maddieson 1996), have been the source of much debate in literature concerning their phonetic implementation, their phonological representation, as well as the way to account for their particular behavior. Within CV phonology, a geminate is represented as a single melodic unit (a bundle of distinctive features characterizing a segment) associated to two prosodic positions (Leben 1980). Such a representation, which relies crucially on the tenet that syllabicity is represented on a separate tier from the melodic one, has subsequently been the received analysis of geminate consonants, including post-lexical geminates (Kenstowicz 1994). The underlying representations of a singleton stop (a), a lexical geminate (b), a geminate created by concatenation of two identical stops across a morpheme boundary (c), and a geminate derived by total assimilation (d) are given in (1) below.

(1)


How are these abstract phonological representations reflected in the phonetic details of speech production? How are these phonetic aspects related to the distinct behavior of different types of geminates, namely their ambiguity (i.e. they behave in some respects as if they were two segments, and in others as if they were one, see Kenstowicz 1970) and their inalterability (i.e. the failure of certain phonological processes to alter lexical geminates while affecting singletons and “fake” geminates, see Hayes 1986b). Two experimental studies are presented in this work. The first experiment examines, based on acoustic and articulatory data, how underlying geminates are phonetically implemented in different word positions, and discusses the phonological relevance of these correlates. The second experiment questions the autosegmental analysis of external sandhi assimilation. Based on acoustic data, the aim is to determine whether phonologically derived geminates, either by concatenation (1c) or by total assimilation (1d), are categorically identical to underlying geminates (1a). The results obtained are discussed in light of the behavior of lexical and post-lexical geminates vis-à-vis the process of spirantization.

Tashlhiyt Berber, the language investigated in this work, is an excellent test case for the study of these issues. This language has all the types of segments represented in (1). And, as illustrated below, lexical geminates are attested in absolute initial and final positions, in addition to the more frequently attested word-intervocalic geminates.

(2)	a.	Singleton	/tut/	[tut]	'she hit'
	b.	Lexical geminate	/ttut/	[ttut]	'forget him'
			/ttutt/	[ttutt]	'forget her'
	c.	Concatenated geminate	/tut tins/	[tuttins]	'she hit hers'
	d.	Assimilated geminate	/rad tut/	[rattut]	'she will hit'

Tashlhiyt Berber is spoken in the Southern part of Morocco. The language is sufficiently homogeneous for all native speakers (who number an estimated 3 million: Chaker 1992) to communicate without difficulties. There is, however, a measure of dialectal variation. Following the work of Boukous (1994), Tashlhiyt Berber may be subdivided into three main dialects: (a) the occlusive dialect spoken in Agadir and its suburbs, (b) the fricative dialect spoken in Haha, where singleton /b, k, g/ are sometimes replaced with /β, x, ɣ/ respectively, and (c) the sibilant dialect spoken in the Anti-Atlas area, where /t/ and /d/ are sometimes replaced by [s] and [z], respectively. This study is concerned with the Tashlhiyt Berber spoken in Agadir and its suburbs (see Ridouane (2007), for a detailed phonetic study on singleton/lexical geminate contrast including speakers from the fricative dialect). The phonemic system of Tashlhiyt Berber is shown in Table 1. Except for the three vowels /a, i, u/, each segment in Table 1 has a geminate counterpart at the underlying level.

Table 1. List of Tashlhiyt Berber phonemes.

Labials	Dentals	Palatoalveolars	Velars	Uvulars	Aryepi glottals	Glottal
	t tˤ		k kʷ	q qʷ		
b	d dˤ		g gʷ			
	n nˤ					
f	s sˤ	ʃ		χ χʷ	ʜ	
	z zˤ	ʒ ʒˤ		ʁ ʁʷ	ʢ	h
w	l lˤ	r rˤ	j			
a			u		i	

2. Experiment 1: Phonetic implementation of lexical geminates

Gemination has been examined in numerous production studies. The main aim of these works was to determine the exact phonetic differences between geminate and singleton consonants. I present a brief review of the main results obtained from some of these studies starting with previous works on Tashlhiyt Berber.

2.1. Previous works on Tashlhiyt Berber geminates

Within CV phonology, Dell and Elmedlaoui (1997) represent a geminate consonant as a single melodic unit linked to two adjacent prosodic slots (see 1b). Arguments in favour of such a non-linear representation of geminates are well established from a cross-linguistic point of view (See Kenstowicz (1994) for a review. See also the phonological and morphological arguments presented in Dell and Elmedlaoui (1997) based on a variety of Tashlhiyt Berber spoken in Imdlawn Valley). However, discussions of geminate consonants within this framework have not been explicit as to which acoustic or articulatory features this representation is supposed to reflect (see Lahiri and Hankamer 1988). Unless they are sufficiently abstract prosodic slots, the distinction between a single linked segment and its double linked counterpart is generally understood as predicting a distinction of consonant length, all other features being the same (see Clements 1986).

The sequence representation of Tashlhiyt Berber geminates (1b) is challenged in numerous studies (e.g. Galand 1988, 1997, Ouakrim 1993, 1994, 1999, Louali and Puech 1994). These authors consider that /tt/ and /t/ are both simple segments that differ in one distinctive feature. In Galand's view, the feature involved is [tense]: /tt/ is [+ tense] and /t/ is [- tense]. The longer duration displayed by geminate consonants is considered, by this author, to be an automatic consequence of their greater articulatory strength or "tension". A major argument generally set out against the sequence representation (1b) is related to the distribution of these segments and the way they are syllabified. Most of these authors adopt the standard view of syllable structure, according to which geminate consonants arise from sharing of articulatory specifications across the coda position of one syllable and the onset position of the next. In this theory, geminates only occur in medial position. Apparent geminates in absolute initial or absolute final positions should on closer examination prove to be distinguished by some other feature, such as tenseness, rather than by length per se. As already shown in (2) above, Tashlhiyt Berber contrasts singletons and geminates in absolute initial position, even for voiceless stops (e.g. [ks] "feed on" *vs.* [kks] "take off"). According to Galand (1997), the fact that duration in initial position cannot distinguish such pairs, since nothing is heard until the release, implies that other correlates are used by Tashlhiyt Berber speakers, such as greater strength of the release, for example. These correlates are considered to be manifestations of the feature [+ tense], which characterises these segments and distinguish them from their [-tense] counterparts.

2.2. Geminates in other languages

In addition to Tashlhiyt Berber, geminates, namely word-medial ones, have been investigated in numerous languages. A review of the main results obtained from 24 such languages is reported in Table 2. This table shows the effect of gemination on the three main temporal parameters examined (closure duration, preceding vowel duration, and release duration).

Table 2. A review of the main temporal acoustic attributes affected by gemination in 24 languages. '++' means that the parameter is highly significant. '+' means that the parameter is significantly affected by gemination though there are some variations (depending either on speakers, contexts, or consonants). '-' means that the parameter is not significantly affected by the presence of gemination. The empty cells indicate that the corresponding parameter has not been investigated.

Languages & References	**Closure duration**	**Prec. vowel duration**	**Release duration**
Buginese (Cohn et al. 1999)	++	++	-
Madurese (Ham 1998, Cohn et al. 1999)	++	++	-
Toba Batak (Cohn et al. 1999)	++	++	-
Swedish (Hassan 2002)	++	++	
Bengali (Lahiri & Hankamer 1988)	++	+	-
Italian (Eposito & Di Benedetto 1999)	++	+	-
Malayalam (Local & Simpson 1988)	++	+	
Rembrranga (Mc Kay 1980)	++	+	
Cypriot Greek (Arvantini & Tserdanelis 2000)	++	-	++
Turkish (Lahiri & Hankamer 1988)	++	-	+
Japanese (Homma 1981)	++	-	-
Palestinian Arabic (Miller 1987)	++	-	-
Iraqi (Hassan 2002)	++	-	

Morrocan Arabic (Zeroual 2006)	++		+
Bernese (Ham 1998)	++		-
Burarran (Baker 1999)	++		-
Hungarian (Ham 1998)	++		-
Jawon (Jaeger 1983)	++		-
Levantine Arabic (Ham 1998)	++		-
Ngalakgan (Baker 1999)	++		-
Zapotec (Jaeger 1983)	++		-
Marathi (Lisker 1958)	++		
Pattani Malay (Abramson 1986)	++		
Tamil (Keane 2002)	++		

The only consistent acoustic characteristic shared by geminates is that they are significantly longer than their singleton counterparts. These systematic durational differences are reported in 100% of the 24 languages reviewed. Lahiri and Hankamer (1988), for example, investigated the timing properties of singleton/geminate voiceless stops in Turkish and Bengali. Their results show that closure duration is the most important correlate of the geminate/singleton opposition for both languages. In addition, VOT is longer for geminates in Turkish while vowel duration is unaffected. In Bengali, vowel duration is shorter before geminates (though not for all subjects), but VOT is unaffected. In addition to temporal differences, singleton/geminate contrast may also be non-temporally implemented. Though these parameters have not been as much investigated as the temporal ones, several studies suggest that the phonetic implementation of gemination may have implications for most if not all of a form’s phonetic shape involving burst amplitude, vowel and consonant qualities and resonances. Local and Simpson (1988, 1999) are illustrative examples of such studies. They showed that, in Malayalam, forms containing geminates differ systematically from those without geminates in terms of phonation, tense vs. lax articulations, consonant and vocalic resonances as well as patterns of articulatory variability in adjacent consonants (see also Payne 2006 for the same observations in Italian).

The phonetic characteristics of initial and final geminates have not been as much investigated as word-medial ones. This fact is unsurprising knowing that these segments are cross-linguistically rare (Davis 1999). Pattani Malay, which presents such geminates, is one of the few languages which has been investigated in depth (Abramson 1986, 1987, 1991, 1999). Results obtained from this language showed significant differences between forms with initial geminate and non-geminate voiceless stops in terms of burst amplitude and the fundamental frequency of the following vowel. A specific aspect concerns the temporal characteristics of such utterance-initial voiceless geminate stops: are they maintained or neutralised? As Abramson (1999: 591) has observed, there can be 'no direct signal of the relative durations of stop closures in utterance-initial position', since they exhibit no vocal tract excitation during their closure period. This makes it impossible to measure closure duration of utterance-initial voiceless stops from the acoustic signal.

There are, however, other means of measuring this duration, such as the aerodynamic measurements of oral airflow (see Ridouane 2003) or the electropalatographic measurements of tongue-to-palate contact over time (see Kraehenmann and Jaeger 2003). This last articulatory procedure is the one used in this study. Under the assumption that the phonetic closure correlates directly with the duration of linguapalatal contact, the aim is to examine whether or not significant temporal differences will be maintained between voiceless singleton and geminate stops in utterance-initial position, though these differences cannot be perceived. In addition to articulatory data, several temporal and non-temporal parameters are investigated acoustically to determine whether duration, rather than tenseness, is the primary correlate that distinguishes singletons from geminates. Assuming a tight relationship between phonetic and phonological representations, this paper seeks to draw a clear mapping between the phonetic properties of geminates and their phonological representation and behavior[1].

2.3. Speech material and Methods

The speech material analysed in this first production study is listed in Table 3. It consists of 36 forms opposing obstruent singletons to their geminate counterparts in three positions.

Table 3. List of stimuli with the target obstruents occurring in 3 positions: initial, intervocalic and final positions.

	Initial	**Intervocalic**	**Final**
t	tid *"those, fem."*	itid *"for those, fem."*	ifit *"he gave it, masc."*
tt	ttid *"soap"*	ittid *"come nearer"*	ifitt *"he gave it, fem."*
k	kif *"like"*	ikin *"earthenware"*	iwik *"your son "*
kk	kkis *"take off"*	ikkis *"he took off"*	imikk *"little"*

d	dis *"with him"*	idis *"stomach"*	ifid *"he gave here"*
dd	ddiʁ *"I went"*	tiddi *"height"*	ibidd *"he stood up"*
g	giʁ *"I am"*	igi *"he was"*	atig *"price"*
gg	ggiz *"go down"*	iggi *"floor"*	°irigg *"non-word"*
s	sin *"two"*	isin *"for two"*	ifis *"jackal"*
ss	ssir *"lace"*	issin *"know"*	ifiss *"he was quiet."*
z	zid *"go forward"*	izid *"he went forward"*	iwiz *"insomnia"*
zz	zzit *"oil"*	izzit *"for oil"*	°ifizz *"non-word "*

These forms are in minimal or near minimal pairs, in which the vowel preceding or following the target segments is the same (i.e. the vowel /i/). In two cases, nonsense words were chosen due to a lack of actual Tashlhiyt Berber words with the relevant structure. Five native male speakers, belonging to the same Tashlhiyt area (Agadir and its suburbs), were asked to read the token words five times in isolation, each time in a different random order. These words were not embedded in a carrier sentence so as to ensure that initial and final obstruents were indeed produced in utterance initial and final positions. Test items were mixed with distracters not containing singleton/geminate contrasts. The data were recorded on a high-quality magnetic tape recording system, and sampled at 44100 Hz. Broad-band spectrograms of all utterances and visual displays of the corresponding waveforms were inspected in Praat (Boersma 2001) to establish measurement criteria. Four temporal and three non-temporal parameters were considered[2]. These parameters constitute some of the most frequently observed acoustic correlates claimed to be involved in the singleton/geminate (or tense/non-tense) opposition.

a. Temporal parameters:

- Duration of the pre-consonant vowel (V1d).
- Closure duration for stops (Cld).
- Consonant duration for fricatives (Frd).
- Release duration (Rld)[3].

b. Non-temporal parameters:

- Lenition (Frication) in stop closures (complete vs. incomplete seals).
- Presence or absence of release (i.e. burst-full vs. burst-less stops).
- Stop release amplitude (Root Mean Square amplitude)[4].

Durational values for utterance-initial singleton and geminate voiceless dental stops were measured on electropalatographic recordings (EPG3), as the duration of the stop articulatory closure. For the annotation of linguapalatal closure duration, the onset was defined as the first frame showing a complete closure on either of the two most anterior rows of electrodes on the pseudopalate, and the offset as the last frame before the partial or total release of contact. In order to provide a statistical analysis of these EPG measurements, the data recorded were composed, in addition to the forms containing initial dental voiceless stops in Table 3, of 4 additional forms presented in Table 4. Each form was recorded ten times by two native speakers. The two subjects were asked to produce the isolated words starting with the mouth slightly ajar such that there was no linguopalatal contact prior to the onset of the word.

Table 4. Additional data recorded using EPG

	Form	**Gloss**
t	tili	*'ewe'*
tt	ttili	*'have'*
t	tut	*'she hit'*
tt	ttut	*'forget him'*

2.4. Results

Figure 1 sums up the effect of gemination on each one of the temporal parameters examined as well as on RMS amplitude of the stop release. It shows the mean durations for each measurement across speakers, repetitions, places of articulation and positions. Vowel durations are pooled across all obstruents (stops and fricatives). Release duration values are presented separately for voiceless and for voiced stops, so as to highlight the differences in gemination effect for these two series of stops.

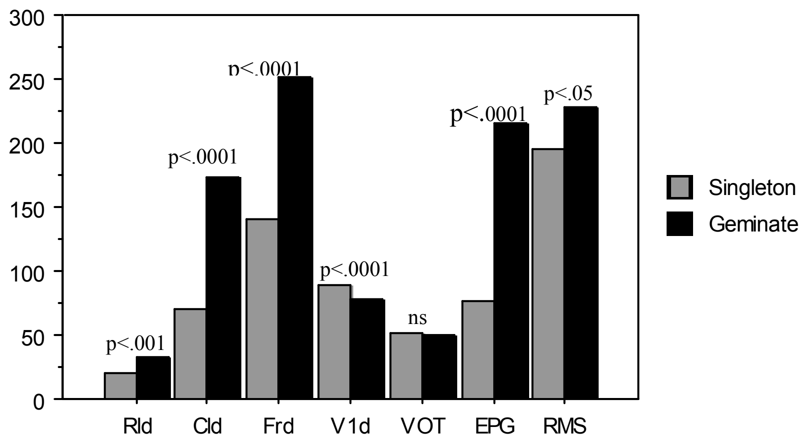


Figure 1. Effect of gemination on some of the parameters examined. (Rld = release duration of voiced stops, VOT = VOT duration of voiceless stops, Cld = closure duration, Frd = fricative duration, V1d = preceding vowel duration, EPG = closure duration of voiceless stops based on EPG data, RMS = RMS amplitude of the stop release).

2.4.1 Temporal parameters

With the exception of VOT duration for voiceless stops, all the other temporal parameters are affected by gemination in all positions. Consonant duration (and closure duration for stops) is the most robust correlate that distinguishes singletons from geminates; the latter being systematically longer than the former ([$F(1, 98) = 528.124$, $p<.0001$] for stops, and [$F(1, 58) = 332.124$, $p<.001$] for fricatives). Results, based on the EPG measurements of linguopalatal contact for the two subjects, also show that these durational differences were systematically maintained for these segments in this position [$F(1, 10) = 116.602$, $p<.0001$].

Characteristics other than closure duration also distinguished geminates from singletons, but less consistently. Release duration was significantly affected by the presence or absence of gemination only for voiced stops ($F(1, 58) = 13.129$, $p <.001$). No such significant differences were observed between the two series of voiceless stops ($F(1, 58) = .065$, $p = .9142$). Similar findings were observed for Moroccan Arabic (Zeroual 2006) and Bengali (Mikuteit and Reetz, ms). Like Tashlhiyt Berber, in these languages, gemination has an effect on the release duration of voiced stops, but not for their voiceless counterparts. In Cypriot Greek, Arvaniti and

Tserdanelis (2001) and Muller (2003) found that the release duration of voiceless stops is significantly affected by the presence of gemination; geminates having a longer aspiration duration than singletons (the Cypriot inventory does not include voiced stops). According to them, this acoustic property is present in order to enhance the differences between the two phonemic categories. In Tashlhiyt Berber, this interpretation is valid for voiced stops only. The occurrence of these differences is probably a consequence of the devoicing which affects geminate stops, so that the more devoiced a segment the longer its release duration (see also Ridouane, 2007). Figure 2 illustrates such a relationship: the form containing the devoiced /dd/ clearly exhibits a longer release duration.

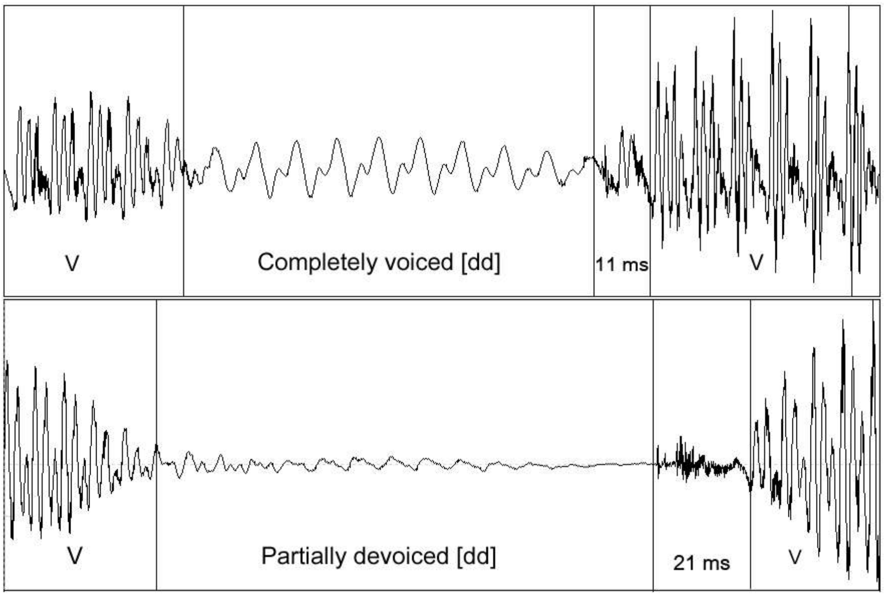


Figure 2. Waveforms of two realisations of an intervocalic voiced geminate stop /dd /. The figure on the top illustrates the realisation of a partially devoiced /dd/. The figure on the bottom illustrates a completely voiced realisation of the same form.

Preceding vowel duration was also found to be significantly affected by gemination; vowels being significantly shorter before geminates in all positions ([$F(1, 58) = 44.359$, $p<.0001$] for intervocalic position, and [$F(1, 58) = 63.615$, $p<.0001$] for final position). The interaction between preceding vowel duration and gemination in intervocalic position has been reported in many languages (33% of the 24 languages presented in Table 2, see also Maddieson 1985). 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). This interpretation is tested through the examination of the effects on vowel duration in forms displaying the same syllable structure (i.e. **V**C.CVC), where CC is either a lexical geminate or a two-consonant cluster. The aim is to determine whether vowel duration will be affected in the same way in both the geminate and the cluster contexts. The items analysed are presented in (3).

(3)	[ikkis] 'he took off'	*vs.*	[iktid] 'he remembers'
	[iffid] 'he pours'	*vs.*	[ifsid] 'he detaches'
	[ibbid] 'he cuts'	*vs.*	[ibdig] 'it is wet'
	[izzin] 'for the beauty'	*vs.*	[iʁzif] 'be long'

These items were read 5 times by 5 Tashlhiyt Berber speakers, each form being embedded in the following carrier sentence: *inna jas … jat twalt* 'he told him … once'. Measurement of the vowel durations shows that vowels are significantly shorter in the geminate context compared to the cluster context [$F(1, 38) = 25.327$, $p<.0001$]. These results show that vowel shortening observed in intervocalic position cannot be considered a consequence of syllable structure differences. Unless the final timing slot is considered to be extrasyllabic, this explanation cannot account for the shortening observed in absolute final position, neither. In this position, the vowel is in a closed syllable for both singleton and geminate environments, but still shorter in the latter. Clearly, the explanation of the vowel shortening observed before geminates is not yet complete and more research is needed to account for the interaction between gemination and preceding vowel duration. A possible interpretation that merits further investigation would be to argue, along with Malécot (1968, 1970), that vowel shortening is due to the human tendency to anticipate relatively great efforts and to delay lesser ones, so that the more energy a consonant is felt to require, the shorter the preceding vowel. According to Malécot, this vowel shortening is the most important characteristic of the feature "tense" (or "force of articulation"), though he does not consider this attribute as an objective reality (see Debrock 1977 for a detailed discussion). Indeed, naive Tashlhiyt Berber speakers often associate the geminate vs. non-geminate opposition to differences in "greater general effort"; the production of geminates is felt to require "more energy" and "stronger articulation". Many authors also associate the geminate opposition with features characterising a “tense” or “strong” articulation. Jakobson et al. (1952) and Jessen (1998), for example, define geminates with the feature [tense], and Kohler (1984) proposes the feature [fortis] to characterise this opposition (see also Catford 1977, Ladefoged and Maddieson 1996). If this interpretation is correct, vowel shortening would thus be an index of the “tense” articulation of Tashlhiyt Berber geminate segments.

2.4.2. Non-temporal parameters

The non-temporal differences observed in this study between singletons and geminates may also correspond to the ones described in literature as being related to a “tense” articulation. Tashlhiyt Berber geminates are, for instance, systematically produced with complete closure, while their singleton counterparts were sometimes lenited and produced with noise leakage. The frequency of incomplete seals varies according to the voiced/voiceless nature of singleton stops as well as to their place of articulation. Voiced singletons are more frequently realised with incomplete closure (7 repetitions) than their voiceless counterparts (2 repetitions). Among the voiced stops, the tendency for incomplete closure is much higher for velars (5 repetitions) than for dentals (2 repetitions). These findings support the contentions in literature that voiced singleton stops are weaker than their voiceless counterparts, and that velars are weaker than dentals (Foley 1977, Lavoie 1996, Ohala 2002); all these singleton stops being weaker than their geminate counterparts.

Another possible manifestation of the “tense” articulation is related to the presence or absence of stops release. Geminate stops are systematically produced with a clearly identifiable noise burst, while singletons are sometimes burst-less. The absence of release, which results from a weaker manifestation of a stop (see Stevens and Keyser 1989), was observed for voiced stops in final position (4 repetitions), due also to the positional weakness characteristic of a coda compared to onset. For geminates, however, release was systematically maintained even in this position. This is unsurprising from a perceptual point of view, since for the perception of the primary correlate (i.e. duration), both starting and end points of this period need to be discernible.

One last manifestation of this “tense” articulation may be related to the higher release amplitude of geminates. As shown in figure (1), geminate stops are produced with significantly higher RMS amplitude, compared to their singleton cognates [$F(1, 38) = 4.804$, $p = .033$], though these differences are not significant for all subjects. Notice, however, that the higher amplitude of the release of geminate stops can also be considered as an automatic consequence of the longer duration of these segments. Other things being equal, a segment with a stop closure held for a longer time will have higher oral air pressure, and greater release amplitude. In other words, higher amplitude might be considered as a concomitant correlate of phonological length and not an independent correlate of the tenseness of geminate stops. This interpretation clearly needs further investigation, and future research should continue to investigate the interrelationships among length and tenseness[5].

2.5. Lexical geminates: representation

Results from the present study are in accordance with a previous study based on different Tashlhiyt dialects (see Ridouane 2007). They show that geminates and singletons are phonetically implemented by different correlates and support the view that this contrast is not limited to the duration of the target segments. Duration can be considered to be the primary correlate since the opposition expressed with it is produced in every context in which the contrast occurs, even for voiceless stops after pause. There is no support in the acoustic results that the longer duration of geminates is only a consequence of their greater articulatory strength or “tension” as assumed by Galand (1997). Rather, it seems that these durational differences result from the intention of Tashlhiyt Berber speakers to maintain a longer duration for geminates[6].

Differences observed in release duration, which were limited to voiced stops, can be considered to be concomitant correlates, since they occur only as a consequence of the devoicing which affects these segments due to their longer duration. Vowel shortening, systematic presence of release burst, complete closure, and higher RMS amplitude, which may be interpreted as manifestations of a “tense” articulation, can be considered to be secondary correlates, since they are either contextually limited or present some variability across subjects. Vowel shortening, for example, is contextually limited since this correlate is present only when the geminate is preceded by a vowel. This correlate cannot be implemented in initial position, nor in the numerous cases where a word is composed of only one geminate obstruent (e.g. [kk] ‘cross’, [ggʷ] ‘wash’, [ʃʃ] ‘eat’, etc.).

The secondary correlates observed in this paper are interpreted as a means used to "enhance" the primary correlate. According to Enhancement Theory, developed by K.N. Stevens and his colleagues (Stevens, Keyser and Kawasaki 1986, Stevens and Keyser 1989, Keyser and Stevens 2006. See Clements and Ridouane (2006) for a review), a distinctive feature is not usually used by itself to contrast lexical items, rather a supplementary *enhancing* feature is conveyed to phonetically increase the salience of the distinctive feature. This is the case, for instance, for the feature [+rounded], which is introduced to enhance the difference between back and front vowels. This feature has the effect of increasing the auditory difference between front and back vowels by increasing their difference in second formant (F2) frequency. Data from Tashlhiyt Berber provide a further example showing that not only feature contrasts, but skeleton-based contrasts between simple and geminate speech sounds can be enhanced in the same way. The secondary correlates serve to enhance the primary correlate by contributing additional acoustic properties which increase the perceptual distance between singletons and geminates. In addition to being more variable than the primary correlate, these enhancing correlates display another property: they can take on distinctive function in cases where the primary correlate is not perceptually recoverable. This is, for instance, the case for voiceless stops after pause, where duration differences between singletons and geminates cannot be detectable by listeners.

Assuming a tight relationship between phonetic and phonological representations (see, for example, Pierrehumbert 1990, Keating 1990), and assuming that this closeness should be reflected in linguistic theory, the phonetic characteristics of Tashlhiyt Berber geminates are better captured by a structural treatment of these segments as two timing units associated to one melodic slot as in (1b). This structural difference is reflected in the observed acoustic and articulatory differences in consonant duration. Phonetic durations are assigned to these representations, allowing for segment-inherent and language-specific durations (see Clements 1986). For example, in Tashlhiyt Berber, geminate stops are more than twice as long than their singleton counterparts, whereas geminate fricatives are somewhat less than twice as long. In Turkish, geminate stops are about three times longer than their singleton counterparts, whereas in Bengali they are less than twice as long (Lahiri and Hankamer 1988). These durations are then adjusted for other factors which may lengthen the duration of these segments (e.g. the widely observed phenomenon of initial and final prosodic lengthening).

2.5. Geminate ambivalence

The phonological representation in (1b) largely solves some problems raised by the properties of geminate consonants. A particular aspect of these segments is that they behave in some respects as if they were two segments, and in others as if they were one, an aspect generally referred to in literature as “geminate ambiguity” or “geminate ambivalence” (Kenstowicz 1970). This representation accounts for the ambiguous behaviour of geminate consonants in the following way: the representation of the geminate is identical to the representation of a single segment in that both are comprised of only one feature bundle. The representation of the geminate is also identical to the representation of two adjacent segments in that both are composed of two prosodic slots (Dell and Elmedlaoui 1997). Rules that require a feature representation mostly affect the quality of the segment, hence affecting geminates and singletons alike, while rules requiring a sequence representation generally affect the quantity of segments, hence affecting geminates and two-consonant sequences alike (Kenstowicz 1994).

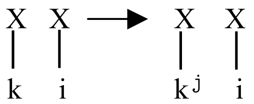
Evidence suggesting that Tashlhiyt Berber geminates behave like single segments comes from a palatalization process (Other examples are presented in Dell and Elmedlaoui (1997) and Galand (1997)). In Tashlhiyt Berber, velars may be realised as palatals before the front vowel /i/ (see Ridouane 1999). This palatalization affects singletons and geminates alike.

(4) Tashlhiyt Berber Palatalization

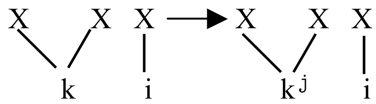
$$\begin{bmatrix}\text{- sonorant}\\ \text{- continuant}\\ \text{- anterior}\\ \text{- coronal}\end{bmatrix} \longrightarrow \begin{bmatrix}\text{- back}\end{bmatrix} \;/\; \_\_\_\_ \begin{bmatrix}\text{- consonant}\\ \text{+ high}\\ \text{- back}\end{bmatrix}$$

The similar patterning of singletons and geminates vis-à-vis the process of palatalization is accounted for straightforwardly in the CV framework. Rule (4) is expressed on the melodic tier where velar stops, be they singletons or geminates, are defined with the same feature bundle. As is demonstrated in (5), the process affects any velar stop immediately preceding the vowel /i/, regardless of whether this segment is singly or doubly linked.

(5) a.

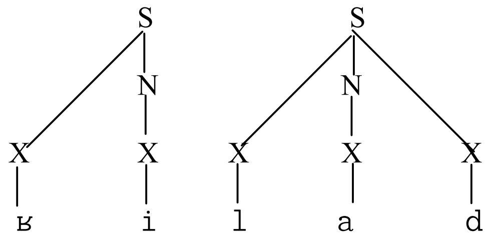


b.

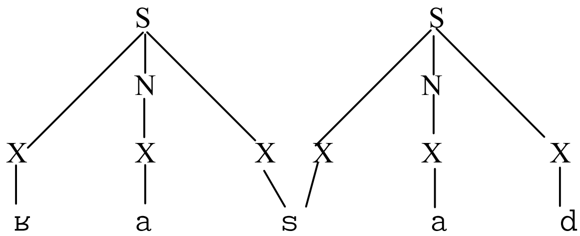


While geminates behave as single segments for some processes, they also pattern like consonant clusters for others. A clear example comes from the way these segments are syllabified. In Tashlhiyt Berber, a geminate consonant, unlike its singleton counterpart, can belong to two syllables at once, and behaves in this respect as a sequence of two consonants. Consider the syllabic parsing in the following examples.

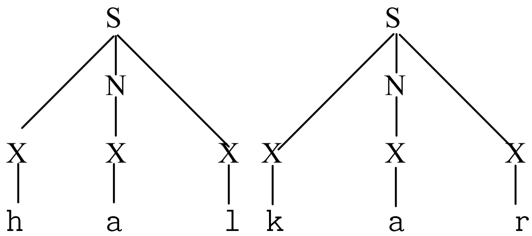
(6) a.[ʁilad]



b. [ʁassad]



c. [halkar]



In (6b), the first half of the geminate is the coda of the first syllable, the second half being the onset of the following syllable. The syllable structure of this form is identical to that of (6c) but different from that of (6a). One main argument in favour of this syllable parsing is drawn from versification. In Tashlhiyt poetry, all the lines of a piece often share the same meter. This meter is characterised by a succession of a definite number of metrical syllables, which are either light or heavy (Jouad 1986). Following the works of Jouad (1986) and Dell and Elmedlaoui (2002), it will be shown below that a Tashlhiyt geminate patterns with a sequence of two segments (i.e. [ʁas.sad] syllabified like [hal.kar]). In the lines given in (7), the pattern is HLHLLLHLHL. (7a) is the first line (and refrain) of a song by a musical group called Iznzarn. (7b) is the first line of a text, well known in the area of Agadir, that modifies Iznzarn's original song while keeping the same metrical pattern. The same text is given in Table 5, broken into nine boxes corresponding each to a metrical syllable.

(7) a. ʁassad izri wa ʁassad izri 'today is gone, oh today is gone'
b. halkar izri wa halkar izri 'the bus is gone, oh the bus is gone'

Table 5. The text in (7) broken into 9 boxes corresponding each to a metrical syllable.

	1	2	3	4	5	6	7	8	9
	H	L	H	L	L	H	L	H	L
a.	ʁas	sa	diz	ri	wa	ʁas	sa	diz	ri
b.	hal	ka	riz	ri	wa	hal	ka	riz	ri

What is worthy of notice here are the syllables in lines 1a and 1b. In the original text, the syllable has a CVC structure, the coda being the first half of the geminate (i.e. ʁas). As is required by the parsing of this verse, in the modified text, the first syllable is also heavy (i.e. hal). The first syllable of the modified text cannot contain a light syllable, otherwise the text would no longer be viewed by Tashlhiyt Berber speakers as a succession of well-formed lines with the same metrical pattern, and can no longer be song in accordance with this parse.

3. Experiment 2: Underlying *vs.* derived geminates

In Tashlhiyt Berber, surface geminates may arise from three different sources. Tautomorphemic lexical geminates, represented underlyingly as single melodic units associated with two timing slots, are given in the lexicon. Heteromorphemic geminates may arise either by concatenation of two identical consonants at a word boundary or by total assimilation. Concatenated geminates are represented underlyingly as two timing slots each associated with a melodic unit. According to McCarthy (1986), these "fake" geminates can be identical to lexical geminates in surface representation, as a result of "Tier Conflation". Assimilated geminates, which arise from the spread of one segment onto the other, are also represented as two timing units associated with a single melodic unit (Hayes 1986b). If these analyses are correct, all three types of geminates, no matter what their underlying representations, will all be identical at the surface level, all being represented as one melodic unit linked to two timing slots. In this second experiment, the three types of geminates are compared so as to determine whether or not they display the same acoustic correlates. Specifically, it questions the autosegmental approach which predicts that the outputs of external sandhi assimilation will fall into categories already established for lexical contrasts. A number of studies, specifically within the gestural overlap model, have in effect cast doubt on this traditional assumption of categorical phonological modifications at word boundaries (Browman and Goldstein 1990, Nolan 1992).

An aspect examined in the light of these instrumentally measurable properties is related to the behaviour of lexical and derived geminates. As is largely established in literature (see Kenstowicz 1994), lexical and assimilated geminates usually behave differently from concatenated geminates vis-à-vis certain phonological processes. The former are, for example, universally unaltered by spirantization, while the latter can be. If inalterability is attributed to phonetic considerations, as is advocated by different authors (Churma 1988, Kirchner 2001), one should then explain why lexical and assimilated geminates pattern together and behave differently from concatenated geminates.

3.1. Speech material and method

The speech material analysed in this second production study is listed in Table 6. It consists of 36 sentences (containing 12 of each type of geminates).

Table 6. List of the three types of geminates examined. Assimilated geminates arise from total assimilation of the preverb final consonant in /ad/ to the following obstruents (e.g. [attasit] from /ad tasit/ "to take).

	Lexical	**Assimilated**	**Concatenated**
/tt/	Innajas ma**tt**a ʁid Innajas ta**tt**uy daʁ	Innajas a**tt**asit Innajas a**tt**awit	Inna tufa**t t**ayri Inna sussa**t t**ama
/dd/	Innajas a**dd**al ns Innajas a**dd**ag ns	Innajas a**dd**aʁ yaf Innajas a**dd**is zrʁ	Inna tʃa**d d**arnʁ Inna tufa**d d**arsn
/kk/	Innajas ta**kk**a nu Innajas a**kk**a jas	innajas a**kk**asiʁ innajas a**kk**a suʁ	inna jufa**k k**arim inna tufa**k k**ullu
/gg/	Innajas a**gg**u nu Innajas a**gg**as nʁ	innajas a**gg**is gaʁ innajas a**gg**im drn	inna waddag **g**ablt inna baddˤa**g g**awrʁ
/ss/	Innajas a**ss**as ʁid Innajas ta**ss**ast ad	Innajas a**ss**is gnʁ Innajas a**ss**al flʁ	Inna tufa**s s**amraw Inna judda**s s**amir
/zz/	Innajas a**zz**an inu Innajas a**zz**ar inu	Innajas a**zz**a ftuʁ Innajas a**zz**a sliʁ	Inna urga**z z**aydat Inna ilba**z z**aydas

The same type of obstruents as in experiment 1 were examined: voiced and voiceless dental stops and fricatives /tt, dd, ss, zz/ as well as voiced and voiceless velar stops /kk, gg/. The same contexts for the three types of geminates were provided. Specifically, each sentence is composed of six syllables, with geminates belonging to the fourth and fifth syllable (the first half being the coda of the 4th syllable and the second half the onset of the 5th syllable). Additionally, all geminate types were preceded by the same vowel /a/. Each sentence was read 5 times by 5 Tashlhiyt native speakers. Five parameters, those affected by gemination in experiment 1, were measured: duration of the preceding vowel (V1d), closure duration (Cld), consonant duration for fricatives (Frd), release duration (Rld), and stop release amplitude.

3.2. Results

Figure 3 sums up the effect of the different types of geminates on each one of the temporal parameters examined. It shows the mean durations for each measurement across speakers, places and manners of articulation. Closure duration and consonant duration for fricatives are pooled together (Cnd).

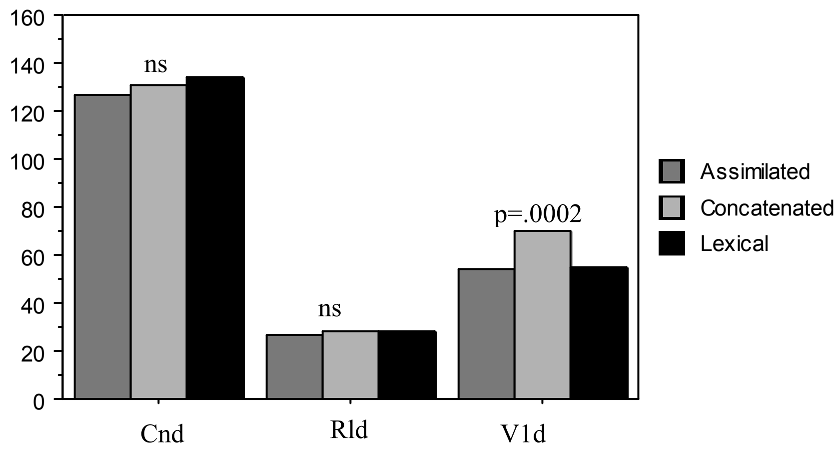


Figure 3. The effect of different types of geminates on the temporal parameters examined.

Results show that the three types of geminates are produced with virtually the same consonant durations (closure duration for stops). The ANOVA analysis performed on this parameter showed that there are no significant differences between lexical, assimilated and concatenated geminates [$F(2, 45) = .711$, $p=.5$]. As is the case for consonant duration, all three types of geminate stops are also produced with virtually the same release durations ([$F(2,12) = 1.388$, $p=.3$], for voiceless stops, and [$F(2,12) =.227$, $p=.8$] for their voiced counterparts).

These results, showing that all three types of geminates display the same durational values (closure duration + release duration for stops), were also obtained by Lahiri and Hankamer (1988) on Bengali. However, contrary to what was found in this language, significant differences are observed in the preceding vowel durations between the three types of geminates in Tashlhiyt Berber [$F(2, 57) = 9.992$, $p=.0002$]. Figure 4, which reports the durational values for these vowels by speakers, shows they are significantly shorter before lexical and assimilated geminates than before concatenated geminates. A Fisher's PLSD post hoc test shows significant differences between lexical and concatenated geminates ($p=.0012$), assimilated and concatenated geminates ($p=.0006$), but no significant differences between lexical and assimilated geminates ($p=.7946$).

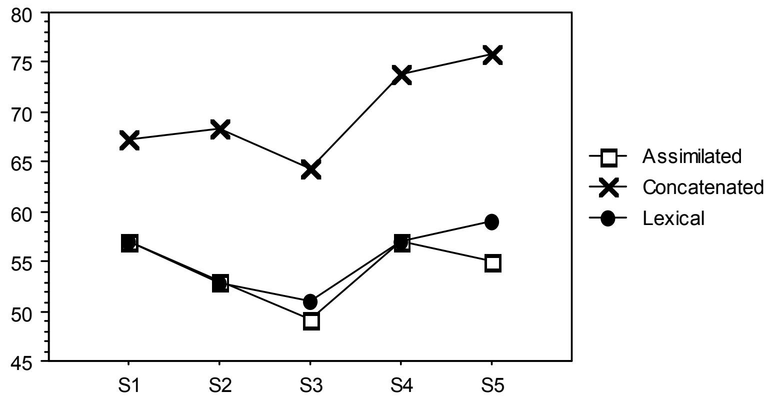


Figure 4. Effect of the three types of geminates on preceding vowel durations.

Another significant difference between the three types of geminates concerns the RMS amplitude of the stop release [F(2, 27) = 4.313, p=.0237]. Results, illustrated in figure 5, show that lexical and assimilated geminates are produced with a higher release energy, compared to concatenated geminates. A Fisher's PLSD post hoc test shows significant differences between lexical and concatenated geminates (p=.0429), assimilated and concatenated geminates (p=.0006), but no significant differences between lexical and assimilated geminates (p=.9780).

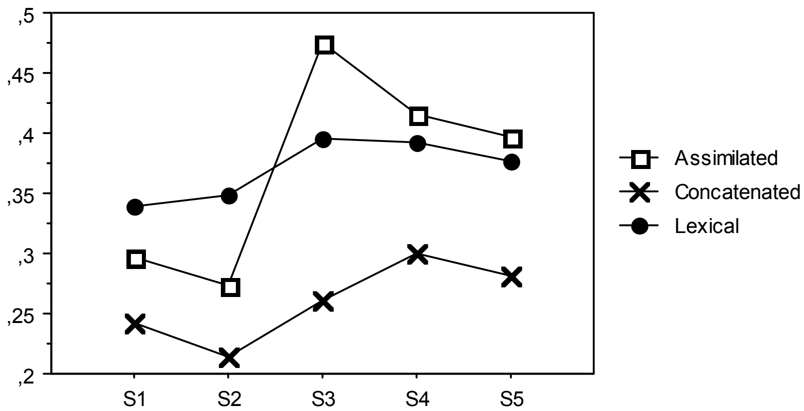


Figure 5. Effect of the three types of geminates on RMS amplitude of stop release.

3.3. Derived geminates: representation and behaviour

The acoustic investigation shows that phonologically derived geminates display the same temporal values as lexical geminates, all being produced with virtually the same consonant durations (closure duration for stops). This supports the assignment of the same timing representation to these three types of geminates (i.e. two timing slots). However, compared to underlying geminates, a major difference has been observed between assimilated and concatenated geminates. While assimilated geminates, like lexical ones, shorten the preceding vowel and are produced with higher RMS amplitude, concatenated geminates do not. Assimilated geminates, being phonetically implemented with additional enhancing correlates, manifest the same characteristics as "true" geminates. This finding, which shows that post-lexical geminates arising from total assimilation are categorically identical to underlying geminates, has also been observed in Sardinian (Ladd and Scobbie 1999). It provides additional evidence that external sandhi assimilation is correctly accounted for within the autosegmental model, in which feature spreading and delinking give rise to multiply-linked structures that are identical to underlying geminates. This model is also sufficient for concatenated geminates, provided they are represented at the surface level as two timing slots each associated with a melodic position. Clearly, the mere fact of having adjacent identical segments is not sufficient in itself to manifest the expected phonetic characteristics of a "true" geminate. Interestingly, in terms of phonological behaviour, lexical and assimilated geminates also pattern together as opposed to concatenated geminates.

In a variety of Tashlhiyt Berber (the Haha variety spoken in the High Atlas area, henceforth HTB), true geminates are not affected by spirantization, while the concatenated ones are. Let us illustrate this phenomenon through the examination of the morphophonemic alternation between singleton spirants and geminate stops displayed in (8).

(8)	Imperative Form	Intensive Form	
a.	ftu	fttu	'to walk'
	ɣnu	ɣnnu	'to sew'
	rz	rzza	'to break'
b.	xrz	kkrz	'to plow'
	ɣn	ggan	'to sleep'
	ʜβu	ʜbbu	'to hide'

The main questions raised by these data concern the representation of the singleton/geminate alternations (8a and 8b), and the spirant/stop alternations (8b). Concerning the singleton/geminate alternation, Dell and Elmedlaoui (1989) developed a set of rules accounting for this phenomenon, and concluded that the geminates in alternating forms should be derived from non-geminate consonants. Concerning the geminate stop/singleton spirant alternation, one must decide in some principled way whether the underlying segment is a stop or a spirant. There appears to be strong evidence for positing underlying single stops and deriving the spirants from these segments. This solution, supported by concepts of markedness and implicational universals, is observationally adequate. The spirantization rule is a synchronic obligatory one; recent Arabic loan words occurring with phonetic non-geminate stops are realised with spirants in HTB, as is shown in (9).

(9)	Moroccan Arabic	HTB	
	lkas	lxas	‘glass’
	ʜkm	ʜxm	‘govern’
	lgzzar	aɣzzar	‘butcher’

The only stable rule under these conditions is a spirantization context-free rule, whereby non-dental singleton stops are spirantized. HTB geminate stops resist the application of this rule:

(10) Singleton spirantization and geminate blockage in HTB

a.	/baba/	βaβa	‘father’
	/akal/	axal	‘land’
	/gawr/	ɣawr	‘sit down’
b.	/tibbit/	tibbit	‘breast’
	/tawkka/	tawkka	‘worm’
	/aggas/	aggas	‘injury’

Why do geminate stops resist the application of spirantization (10b), though it applies to their singleton counterparts (10a)? In other words, why does spirantization fail to turn the geminate bb’s into geminate ββ’s? This inalterability of geminates is a universal characteristic observed in different unrelated languages (e.g. Tiberian Hebrew, Tigrinya. See Kirchner (2001) for a review). Different proposals have been posited to account for it (e.g. Hayes’ (1986a) Linking Constraint, Schein and Steraide’s (1986) Uniform

Applicability Condition). In a criticism of these proposals as mere notional machinery restating observational facts instead of predicting significant generalisations, Churma (1988) argues that recognising a distinction between “weakening” and “strengthening” rules will allow for a theory which has significantly greater predictive power (see also Foley 1977, Elmedlaoui 1993, Kirchner 2001). In particular, he argues that it is the inherent “strength” of geminate consonants that prevents a weakening process like spirantization from affecting them. Churma (1988), along with Foley (1977) and Hooper (1976), places geminate consonants at the bottom rung of the sonority hierarchy, i.e. at the top rank of the inherent segmental strength. A slightly different account of geminate strength has been proposed by Elmedlaoui (1993), who sees in gemination rather a positional and metrical or moraic property, and places geminates at the top rank of positional strength. Besides these phonological hypotheses on geminate tenseness or « strength » (Hooper 1976, Foley 1977, Churma 1988, Elmedlaoui 1993), this property is in the present work on a phonetic ground. In addition to their extra duration, lexical geminates are shown to display characteristics of a strong articulation, the manifestations of which are mainly related to the shortening of the preceding vowel, the higher RMS amplitude of the release, the systematic absence of noise leakage during closure, and the systematic presence of stop releases.

Assimilated geminates, like lexical geminates, are also shown to display the same tenseness characteristics. Interestingly, this type of geminates also resist the application of this weakening process, as is shown in (11).

(11) Spirantization Blockage in assimilated geminates

/rad-k-awin/	rakk awin	(*raxx awin)	‘they will take you’
/rad-gis gaʁ/	raggis ɣaʁ	(* raɣɣis ɣaʁ)	‘I will put in it’

Concatenated geminates, on the other hand, are affected by spirantization, as data in (12) demonstrate. The weakening observed here is due to the failure of the concatenated segments to surface with the same enhancing correlates as true geminates, and thus display characteristics of a "tense" segment. In other words, concatenated geminates are not “strong” enough to resist the application of this weakening process.

(12) Spirantization of concatenated geminates

/jufak kiyyi/	jufax xiyyi	‘it is better for you’
/imrg gma/	imrɣ ɣma	‘my brother was ashamed’

As Churma observed, aside from degemination, no non-assimilatory weakening process may affect strong consonants (see also Foley 1973). A parallel may be made between this observation and a rather unexpected property displayed by enhancing correlates. Based on numerous examples drawn from different languages, Keyser and Stevens (2006) observed that while the basic correlates are, in certain contexts, subject to weakening or obliteration, enhancement correlates are far more robust and are apparently never weakened or obliterated. In Tashlhiyt Berber, the enhancing correlates of geminate stops, those responsible for the strength displayed by these segments, also resist the application of weakening rules. In other words, once introduced to reinforce existing contrasts between two sounds, the enhancing correlates tend to survive, and may eventually supplant the basic correlate which they originally served to enhance (the case of utterance initial voiceless stops).

4. Conclusion

In Tashlhiyt Berber, the primary correlate distinguishing singletons from lexical geminates is duration, even for voiceless stops after pause. This primary correlate is enhanced by additional acoustic attributes (such as vowel shortening, higher RMS amplitude, complete closure, systematic presence of stop release). These enhancing correlates may be present in order to increase the perceptual distance between the two phonemic categories, and may take on a distinctive function if the primary correlate is not perceptually recoverable. The acoustic and articulatory characteristics of geminates are captured within CV phonology by a structural representation of these segments as two timing units associated to one melodic slot, and for an interpretation of that representation according to which the relevant timing measure is the duration of the consonant (and of closure duration for stops). Such a representation, as shown by data drawn from a palatalization process and syllabification, correctly accounts for the dual behaviour of geminates. The comparison between lexical and phonologically derived geminates shows that they all display the same temporal values, which supports the assignment of the same timing representation to these three types of geminates. However, a major difference between assimilated and concatenated geminates has been observed. While assimilated geminates, like underlying ones, are enhanced by additional acoustic attributes, concatenated geminates are not. Interestingly, in terms of behaviour, lexical and assimilated geminates also pattern together as opposed to concatenated geminates. The former are, for example, unaltered by spirantization while the latter is. In order to account for the distinct behaviour of these segments, a distinction was made between “true” and “fake” geminates. True geminates, including lexical and assimilated geminates, are phonetically implemented by additional correlates, which account for the “strength” displayed by these segments. Following Churma (1988), I argue that it is the "strength" of these geminate stops that prevents any weakening process (such as spirantization) from affecting them.

Notes

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[1] Hereafter, the term geminate will be used in a generic sense, with a distinction at the phonological level of *phonological length* and *tenseness*. The phonetic results will be evaluated accordingly with phonetic duration mapping to phonological length and other cues (such higher RMS amplitude) mapping to tenseness.

[2] See Ridouane (2007), for a detailed description of the criteria established to measure these acoustic attributes.

[3] This parameter was determined as the temporal interval between the onset of release noise (the first burst if multiple bursts are present) and the onset of F2 of the following vowel. For stops in final position, the release was calculated as the interval between the onset and the offset of release noise.

[4] Root Mean Square (RMS) amplitude was measured over the release duration of singleton and geminate voiceless stops. The RMS amplitude is not an absolute measure since it can be affected by the general loudness of the utterance, for example. To ensure that the comparisons were not affected by such differences, the RMS values were normalised by dividing the RMS of the release portion by that of the following vowel. The measurements were thus limited to initial and intervocalic stops.

[5] This issue is the source of much debate in other unrelated languages (see for example Ham (1998) and Kraehenmann (2001) on this controversy in High Alemannic and Swiss German literature, and Han (1996) and Kim (2004) and the references therein on geminate vs. tense analysis of Korean consonants).

[6] In a recent paper, Löfqvist (2005) proposes a plausible mechanism to explain how this duration is controlled. According to him, geminates are produced with a more extreme target position, compared to singletons. With a more extreme constriction target, the articulators will keep moving longer towards that goal, and thus the closure interval will be longer.

References

Abramson, Arthur S.
1986 The perception of word-initial consonant length: Pattani Malay. *Journal of the International Phonetics Association* 16, 8-16.

Abramson, Arthur S.
1987 Word-initial consonant length in Pattani Malay. *Proceedings of the 11th International Congress of Phonetic Sciences, vol. 6.*

Abramson, Arthur S.
1991 Amplitude as a cue to word-initial consonant length: Pattani Malay. *Proceedings of the 12th International Congress of Phonetic Science*, 98-101.

Abramson, Arthur S.
1999 Fundamental frequency as a cue to word-initial consonant length: Pattani Malay. *Proceedings of the 14th International Congress of Phonetic Science*, 591-594.

Arvaniti, Amalia and Georgios Tserdanelis
2000 On the phonetics of geminates: evidence from Cypriot Greek. *Proceedings of the International conference on Spoken Language Processing.* *http://ling.ucsd.edu/~arvaniti/01450.zip*

Arvaniti, Amalia and Tserdanelis, Georgios
2001 The acoustic characteristics of geminate consonants in Cypriot Greek. *Proceedings of the 4th International Conference on Greek Linguistics*: 29-36. *http://ling.ucsd.edu/~arvaniti/TandA.zip*

Baker, Brett
1999 *Word structure in Ngalakgan*. Ph.D. Dissertation, University of Sydney. *http://pollux.library.usyd.edu.au/~thesis/adt-NU/public/adt-NU2000.0003/*

Boersma, Paul
2001 Praat, a system for doing phonetics by computer. *Glot International*, 5(9-10), 341-345.

Boukous, Mohamed
1994 Variation phonique et compétence globale: le cas du parler d'Agadir. *Publications de la Faculté des Lettres.* Rabat.

Browman, Catherine P. and Louis Goldstein
1990 Tiers in articulatory phonology, with some implications for casual speech. In J. Kingston and M.E. Beckman (eds.), *Papers in Laboratory Phonology I: between the grammar and physics of speech*. Cambridge: Cambridge University Press, 341-376.

Catford, John C.
1977 *Fundamental problems in phonetics*. Edinburgh: University Press.

Churma, Donald
1988 *On 'on geminates'*. Ms., Suny-Buffalo.

Chaker, Salem
1992 *Textes en Linguistique Berbère : Introduction au Domaine Berbère* Paris : Editions d'Harmattan.
Clements, Nick G.
1986 Compensatory lengthening and consonant gemination in LuGanda. In L. Wetzels and E. Sezer (eds.), *Studies in compensatory lengthening*. Dordrecht: Foris, 37-77.
Clements, Nick G. and Rachid Ridouane
(2006). Part I: Quantal Phonetics and Distinctive Features: a Review. Part II: Distinctive Feature Enhancement: a Review. Proceedings of ISCA Tutorial and Research Workshop on Experimental Linguistics, 17-24 and 28-30.
Cohn, Abigail, William Ham, and Robert Podesva
1999 The phonetic realization of singleton-geminate contrasts in three languages of Indonesia. *Proceedings of the 14th International Congress of Phonetic Sciences, 587-590.*
Davis, Stuart
1999 On the representation of initial geminates. *Phonology* 16: 93-104.
Dell, François and Mohamed Elmedlaoui
1989 Clitic ordering, morphology and phonology in the verbal complex of Imdalwn Tashlhiyt Berber. Part I. *Langues Orientales Anciennes Philologie et Linguistique* 2, 165-194.
Dell, François and Mohamed Elmedlaoui
1997 Les géminées en berbère. *Linguistique Africaine* 19, 5-55.
Dell, François and Mohamed Elmedlaoui
2002 *Syllables in Tashlhiyt Berber and in Moroccan Arabic*. Kluwer Academic Publications.
Elmedlaoui, Mohamed
1993 Gemination and spirantization in Hebrew, Berber, and Tigrinya: a fortis-Lenis module analysis. *Linguistica Communicatio* V, 1, 121-176.
Esposito, Antonietta and Mario Di Benedetto
1999 Acoustical and perceptual study of gemination in Italian stops. *Journal of the Acoustical Society of America* 106, 2051-2062.
Foley, James
1977 *Foundations of phonological theory*. Cambridge University Press
Galand, Lionel
1988 Le berbère. In Cohen and Perrot (eds.), *Les langues dans le monde ancien et moderne. Troisième partie : les langues chamito-sémitiques,* 207-242. Paris : Editions du CNRS.

Galand, Lionel
1997 Les consonnes tendues du berbère et leur notation. In Miloud Taïfi (ed.), *Voisinage, Mélanges en hommage à la mémoire de Kaddour Cadi*, 99-120. Dhar El Mahraz – Fès. Publications de la Faculté des Lettres et des Sciences Humaines.

Ham, William
1998 *Phonetic and phonological aspects of geminate timing*. Ph.D. Dissertation, Cornell University.

Han, Jeong-Im
1996 *The phonetics and phonology of "tense" and "plain" consonants in Korean*. Ph.D. Dissertation, Cornell University.

Hassan, Zeki M.
2002 Gemination in Swedish and Arabic with a particular reference to the preceding vowel duration. An instrumental and comparative approach. *Proceedings of Fonetik 2002 TMH-QPSR* Vol.44, 81-85. http://www.speech.kth.se/qpsr/tmh/2002/02-44-081-084.pdf

Hayes, Bruce
1986a Inalterability in CV phonology. *Language* 62, 321-351.

Hayes, Bruce
1986b Assimilation as spreading in Toba Batak. *Linguistic Inquiry* 17, 467-499.

Homma, Yayoi
1981 Durational relationship between Japanese stops and vowels. *Journal of Phonetics* 9, 273-281.

Hooper, Joan
1976 *An Introduction to Natural Generative Phonology*. New York: Academic Press.

Jaeger, Jeri J.
1983 The fortis/lenis question: evidence from Zapotec and Jawon. *Journal of Phonetics* 11, 177-189.

Jakobson, Roman, Gunnar Fant, and Morris Halle
1952 *Preliminaries to speech analysis: The distinctive features and their correlates*. Cambridge, Mass.: M.I.T. Press.

Jessen, Michael
1998 *Phonetics and phonology of tense and lax obstruents in German.* John Benjamins Publishing Company, Amsterdam/Philadelphia.

Jouad, Hassan
1986 Mètres et rythmes de la poésie orale en berbère marocain. *Cahiers de Poétique comparée* 12: 105-127.

Keane, Elinor
2001 *Echo words in Tamil*. Ph.D. Dissertation, Merton College, Oxford. http://users.ox.ac.uk/~sjoh0535/Thesis/TitleandContents.pdf

Keating, Patricia
1990 Phonetic representations in a generative grammar. *Journal of Phonetics* 18: 321-334.
Kenstowicz, Michael
1970 On the notation of vowel length in Lithuanian. *Papers in Linguistics* 3, 73-113.

Kenstowicz, Michael
1994 *Phonology in generative grammar*. Blackwell Publishers.
Keyser, Samuel Jay and Kenneth N. Stevens
2006 Enhancement and overlap in the speech chain. *Language* 82.1, 33-63.
Kim, Hyunsoon
2004 The representation of the three-way laryngeal contrast contrast in Korean consonants. In van Oostendorp, M. & van de Weijer, J. (eds.), *The Internal Organization of Phonological Segments,* 263–293. Berlin: Mouton de Gruyter.
Kirchner, Robert
2001 *An Effort Based Approach to Consonant Lenition*. London: Routledge.
Kraehenmann, Astrid
2001 Swiss German stops: geminates all over the word. *Phonology* **18**, 109–145.
Kraehenmann, Astrid and marion Jaeger
2003 Phrase-initial geminate stops: articulatory evidence for phonological representation. *Proceedings of the 15th International Congress of Phonetic Sciences*, ICPHS 2003, Barcelona, 2725-2728.
Kohler, Klaus
1984 The phonetic explanation in phonology: The feature fortis/lenis. *Phonetica* 41, 150-174.
Ladd, Robert and James M. Scobbie
2003 External sandhi as gestural overlap? Counter-evidence from Sardinian. In Local, J., Ogden, R. and Temple, R. (eds.), *Papers in Laboratory Phonology VI: Phonetic Interpretation.* Cambridge: Cambridge University Press, 164-182.
Ladefoged, Peter and Ian Maddieson
1996 *The sounds of the world's languages.* Blackwell Publishers: Oxford.
Lahiri, Aditi and Jorge Hankamer
1988 The timing of geminate consonants. *Journal of Phonetics* 16: 327-338.
Lavoie, Lisa M.
1996 Consonant strength: results of a data base development project. *Working Papers of the Cornell Phonetics Laboratory* 11, 269-316.
Leben, William
1980 A metrical analysis of length. *Linguistic Inquiry* 11, 497-510.

Lisker, Leigh
1958 The Tamil occlusives: short *vs.* long or voiced *vs.* voiceless? *Indian Linguistics, Turner Jubilee* I, 294-301.
Local, John and Adrian Simpson
1988 The domain of gemination in Malayalam. In Bradley, Henderson and Mazaudon (eds.), *Prosodic analysis and Asian Linguistics: to honour R.K. Sprigg,* 33-42. Pacific Linguistics.
Local, John and Adrian Simpson
1999 Phonetic implementation of geminates in Malayalam nouns. *Proceedings of the 14th International Congress of Phonetic Sciences* 1, 595-598
Löfqvist, Anders
2005 Lip kinematics in long and short stop and fricative consonants. Journal of the Acoustical Society of America, 117 (2), pp. 858-878.
Louali Naima, and Gilbert Puech
1994 Les consonnes 'fortes' du berbère : indices perceptuels et corrélats phonétiques. *Actes des 20e Journées d'Étude sur la Parole*, 459-464.
Maddieson, Ian
1985 Phonetic cues to syllabification. In V. Fromkin (ed.). *Phonetic Linguistics. Essays in Honor of Peter Ladefoged.* New York: Academic Press. 203-221.
Malécot, André
1968 The force of articulation in American stops and fricatives as a function of position. *Phonetica* 18, 95-102.
Malécot, André
1970 The lenis-fortis opposition: its physiological parameters. *Journal of the Acoustical Society of America* 47, 1588-1592.
McCarthy, John J.
1986 OCP effects: Gemination and antigemination. *Linguistic Inquiry* 17, 207-263.
McKay, Graham
1980 Medial stop gemination in Rembarrnga: a spectrographic study. *Journal of Phonetics* 8, 343-352.
Mikuteit, Simone and Henning Reetz
Ms The timing of aspiration and voicing in East Bengali. Paper resubmitted to *Language and Speech* (25th October 2005).
Miller, Ann
1987 Phonetic characteristics of Levantine Arabic geminates with differing morpheme and syllable structures. *Ohio State Papers from the Linguistics Laboratory* 36,120-140.
Muller, Jennifer S.
2003 The production and perception of word initial geminates in Cypriot Greek. *Proceedings of the 15th International Congress of Phonetic Sciences*, ICPHS 2003, Barcelona, 1867-1870.

Nolan, Francis

1992 The descriptive role of segments: evidence from assimilation. In G.J. Docherty and D.R. Ladd (eds.), *Papers in Laboratory Phonology II: Gesture, Segment, Prosody.* Cambridge: Cambridge University Press, 261-280.

Ohala, Manjari

2002 Somme patterns of unscripted speech in Hindi. In *Patterns of Speech Sounds in Unscripted Communication*. IPDS. Kiel [Abstract]. http://www.ipds.uni-kiel.de/symposium/Abstracts/MOhala.html

Ouakrim, Omar

1993 *Fonética y fonologia del Bereber.* Ph. D. Dissertation. Universitat Autònoma de Barcelona.

Ouakrim, Omar

1994 Un paramètre acoustique distinguant la gémination de la tension consonantique. *Études et Documents Berbères* 11, 197-203.

Ouakrim, Omar

1999 A perceptual study of tenseness. Some acoustic cues identifying tense *vs* non-tense contrast in Berber. *Proceedings of the 15th International Congress of Phonetic Sciences*, ICPHS 2003, Barcelona, 795-798.

Payne, Elinor

2006 Non-durational indices of Italian geminate consonants. *Journal of the International Phonetic Association* 36(1), 83-95.

Pierrehumbert, Janet

1990 Phonological and phonetic representation. *Journal of Phonetics* 18: 375-394.

Ridouane, Rachid

1999 *La spirantisation dans un parler berbère du Maroc (parler chleuh de Haha).* Diplôme d'Etudes Approfondies, Université Paris 3.

Ridouane, Rachid

2003 Suites de Consonnes en Berbère: Phonétique et Phonologie. Ph D. Dissertation. Sorbonne Nouvelle University, Paris 3.

Ridouane, Rachid

2007 Gemination in Tashlhiyt Berber: an acoustic and articulatory study. J*ournal of the International Phonetic Association* 37 (2), 119-142.

Schein, Barry and Donca Steriade

1986 On geminates. *Linguistic Inquiry* 17, 691-744.

Stevens, Kenneth N., and Samuel Jay Keyser

1989 Primary features and their enhancement in consonants. *Language* 65, 81-106.

Stevens, Kenneth N., Samuel Jay Keyser, and Haruko Kawasaki

1986 Toward a phonetic and phonological theory of redundant features. In Perkell and Klatt (eds.), *Invariance and Variability in Speech Processe*s, 426-463. New Jersey: Lawrence Erlbaum Associates.

Zeroual, Chakir
2006 Etude par transillumination des occlusives simples et géminées de l'arabe marocain. *Actes des 26^es Journées d'Etudes sur la Parole*, 465-469.