Phonetics and phonology of Tashlhiyt geminates: An overview

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Abstract. Length functions as an important element of lexical contrast, opposing singletons and geminates in various unrelated languages all over the world. A growing body of research has been conducted on the phonetics and phonology of this contrast over the last few decades. This chapter offers a general overview into this research, focusing on gemination in Tashlhiyt. It provides a concise summary of previous and ongoing research, including the nature of the phonological representation of gemination, and how the articulatory and acoustic-perceptual characteristics of geminates account for their phonetic pattern. Tashlhiyt is an excellent case in point since, most unusually, it has contrastive geminates initially and finally as well as medially, and presents different types of geminates, including lexical, morphological and phonological geminates.

Keywords: Gemination, length contrast, duration, tenseness, Autosegmental Phonology, acoustics, articulation, perception.

1. Introduction

Tashlhiyt opposes any single consonant with a lexical geminate counterpart. As the examples in (1) show, this contrast is attested in various different positions in the word[1].

(1)				
	[**t**ut]	*"she hit"*	[**tt**ut]	*"forget him"*
	[ti**d**i]	*"sweat"*	[ti**dd**i]	*"height"*
	[ifi**s**]	*"hyena"*	[ifi**ss**]	*"he is silent"*
	[iʁ**d**]	*"ash"*	[iʁ**dd**]	*"regarding"*
	[**kk**s**tt**]	*"take it (fem) off"*	[**k**s**t**]	*"feed it (m) on"*

Geminates in Tashlhiyt occur in intervocalic position, the most common position across languages, but also in absolute initial and final positions, positions where geminates are cross-linguistically rare (Taylor 1985, Thurgood 1993, Muller 2001, Dmitrieva 2012). Even rarer, they can be preceded or followed by one or more consonants, and a word may consist of only a geminate (e.g. [ʃʃ] *"eat"*, [gg^{w}] *"wash"*).

In addition to lexically given geminates, Tashlhiyt also has phonologically derived and morphologically derived geminates. Phonological geminates derive either from a total assimilation between two adjacent segments (e.g. between /d/ and /k/ in /rad-k awi-ʁ/ [rakk awiʁ] *"I will take you")* or from a concatenation of two identical segments across a word boundary (e.g. [tuf=fas] *"it's better than Fès"*). Morphological geminates derive from morphological processes such as the derivation of plurals (2a) or the formation of imperfective (2b)[2].

[1]Geminates are not infrequent in Tashlhiyt words, although still far less frequent than their singletons counterparts. In Alderete et al. (this volume), based on a corpus of nine texts with 18,827 word tokens, 19% out of 37334 sound tokens are geminates. Some geminate consonants are, however, marginally attested in the lexicon (especially pharyngeals, laryngeals, labialized uvulars and pharyngealized coronals).

[2]On imperfective gemination, see Dell and Elmedlaoui (1991, 2013), Jebbour (1999), Bensoukas (2001), Lahrouchi (2008, 2010), among others.

(2) a.

Singular	Plural	
afu**s**	ifa**ss**n	*"hand"*
ad^{ʕ}a**r**	id^{ʕ}a**rr**n	*"foot"*
afud	ifa**dd**n	*"knee"*

b.

Aorist	Imperfective	
g**r**u	g**rr**u	*"gather"*
n**k**r	n**kk**r	*"stand up"*
ʁr	a**qq**ra	*"read"*

This chapter focuses on the phonetics and phonology of gemination. The term "gemination" will be used in a generic sense with a phonological distinction between phonological length and tension. Phonetic data on this contrast will be evaluated accordingly, with phonetic duration referring to phonological length, and other correlates (e.g., intensity of release) referring to the [tense] feature. A central contentious issue, which forms the thread of this chapter, is how duration implements the gemination contrast in Tashlhiyt (given the high variability that characterizes this attribute), and how additional correlates may enhance this contrast in case duration is not perceptually recoverable. The structure of this chapter is as follows: section 2 discusses the nature of phonological representation of gemination, including an overview of arguments provided by proponents of a sequential approach and proponents of a feature distinction. Section 3 discusses acoustic and articulatory correlates of gemination, and the necessity for positing one primary attribute – duration – and additional enhancing attributes. Section 4 discusses the perception of geminates, with a special focus on the contrast between singleton and geminate voiceless stops in word-initial position. Section 5 provides a summary of two additional issues not dealt with in detail in this chapter: the phonetic and phonological patterns of different types of geminates, and the effect of speech rate in the way the singleton/geminate contrast is acoustically implemented. Section 6 concludes this chapter with a brief summary and an outlook on areas for which more work is needed.

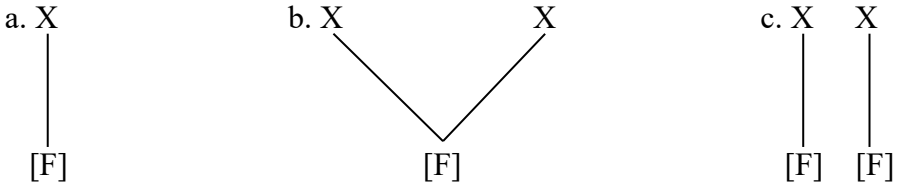
2. Representation of consonant gemination

One of the classic questions in geminate phonology is whether a geminate is a single unit or a sequence of two identical units. This question, clearly posed and debated since the 1930s (e.g., Swadesh 1937, Trubetzkoy 1949), refers to the ambiguous behavior of this segment: sometimes it patterns as a single consonant and sometimes as a sequence of two consonants. Chomsky and Halle (1968), in *Sound Pattern of English*, presented two ways of phonologically representing a geminate: as a segment specified by the [+long] feature or as a sequence of two segments specified by identical feature bundles. Post-SPE work quickly pointed out the shortcomings of such a description and demonstrated that neither representation could adequately account for the way geminates behave with respect to certain phonological processes (Kenstowicz 1970, Pyle 1971, Kenstowicz and Pyle 1973).

The work carried out within the framework of standard generative phonology did not provide a satisfactory answer to the problem of geminates representation, but it had the merit of having identified this problem and of having suggested a generalization that would prove to be very promising (Kenstowicz 1994). Kenstowicz (1970), for example, noted that geminates are generally treated as a single unit by quality-sensitive rules (i.e., sensitive to the internal

composition of segments), and as two units by quantity-sensitive rules (i.e., the number of segments). This distinction between quantitative and qualitative rules is formally developed in the framework of CV Phonology (Leben 1980, Clements and Keyser 1983). The basic idea of CV phonology is that syllable positions are represented on a prosodic tier (typically marked as X slots) separate from the melodic tier (containing segmental features [F]). The two tiers are linked by association lines. This approach allows the following structural representations for geminates in Tashlhiyt (Dell and Elmedlaoui 1997, Ridouane 2003):[3]

(3)



The representation (3a) is that of a single segment linked to a single prosodic position. (3b) is the representation of a geminate consonant. Geminate consonants are distinguished from simple consonants, not by a distinctive feature, but by the number of prosodic positions they contain: the singleton is associated with one prosodic position (3a) and the geminate with two prosodic positions (3b). (3c) illustrates the representation of a sequence of two adjacent consonants. Representation (3b) adequately captures the ambivalence of geminates: it is identical on the one hand to that of singletons since both have a single melodic position (compare 3b to 3a), and on the other hand to that of a sequence of two adjacent consonants since both have two prosodic positions (compare 3b to 3c).

A related important question concerning the representation of geminates concerns the nature of the phonetic opposition between singletons and geminate: is it one of duration or tenseness? Most of the research done within an autosegmental approach have not dealt with this question in much detail. Indeed, marked at the level of syllabic structure, the distinction between one or two prosodic positions is sufficient to account for the difference between singletons and geminates with respect to phonological processes. On the other hand, those who argue that geminates and singletons are distinguished by a distinctive feature are naturally concerned with the nature of that feature, being [+/-long] or [+/- tense].

The feature [tense] has been used in various ways in relation to different consonantal systems (see Jessen (1998) for a review). Linguists who use this feature to define gemination in Amazigh generally use it to denote increased strength or articulatory energy (Mitchell 1957, Applegate 1958, Galand 1953, 1997, Chaker 1975, Ouakrim 1994, Louali and Puech 1994)[4]. Louali and Puech (1994), based on perceptual, aerodynamic and acoustic data, examined whether geminate stops in Tashlhiyt are long consonants or tense consonants. The acoustic analyses show that the duration of geminates is always longer than the duration of their singleton counterparts. Examination of the perceptual data shows that the native speakers use duration as a primary cue to distinguish geminates from singletons. However, they appear to rely on additional cues in a subsidiary manner. The aerodynamic study highlights on the one hand the duration as a distinctive parameter and on the other hand a difference in the profiles of the oral pressure (OP) curves, the curves reflecting the OP indicating for geminates a fast and important rise at the time of the release. Another correlate associated with the realization of geminates is reflected by the quality of the energy of the release which is more intense for geminates (located between 1000 Hz and 2000 Hz).

[3] Moraic representation is another structural representation of geminates, but unlike the representation in (3b), moraic approach assumes that a geminate is inherently moraic (Hayes 1989). For the moraic representation of Tashlhiyt geminates, see Jebbour (19996, 1999).

[4] See also Jakobson, Fant and Halle (1952) and Jessen (1998) who define geminates by the feature [tense], and Kohler (1984) who proposes the feature [fortis] to characterize this opposition.

Ouakrim (1994) explicitly distinguishes geminates, which according to him should only refer to sequences of two identical consonants separated by a morphological boundary (i.e., representation (3c) above), from tense consonants which cannot be subdivided into two phonetic segments or between two syllables. For Ouakrim (1994), the longer duration of tense segments is a manifestation of the physiological energy involved in their production, whereas during the holding of geminates, the speaker subjectively maintains the same effort as in non-geminates or non-tense consonants. One basic correlate of tenseness is the shorter duration of preceding vowels, a shortening which Ouakrim (1994) has not observed in the context of heteromorphemic geminates.

Galand (1953), who was among the first to suggest that geminates are tense consonants, argues that the relevant feature that distinguishes singletons from geminates is muscle tension. A set of arguments is presented by Galand (1997) in favor of this analysis. A first observation concerns their presence in positions where it is impossible to consider them as hinging between two syllables: the initial (e.g. [kks] "take off") and final (e.g. [juff] "it is swollen") positions[5]. Another argument in favor of the [tense] feature according to Galand (1997) is that tension seems to be the feature most likely to explain some phenomena related to geminate distribution. In Tashlhiyt, as well as in other Amazigh varieties, when a simple consonant and its geminate counterpart do not have the same feature [continuant], it is always the geminate that is [-continuant] and the singleton is [+continuant] (e.g., when the singleton [ʁ] alternates with the geminate [qq], as in (2) above). Also, when a singleton and its geminate counterpart have realizations that differ in voicing, it is always the singleton that is [+voiced] and the geminate [-voiced], e.g. ([dˤ] ≈ [ttˤ]). For Galand (1997), duration cannot explain these phenomena:

> *"it is not inconceivable [...] that a badly dosed muscular energy acted, by excess or by defect, on the movements of the speech organs. This would not be the only case in which such blunders would have been accepted and, as it were, consecrated by phonology"* (Galand 1997:106)[6].

Muscular tension would thus explain the tendency of geminates to counteract vocal cord vibration[7]. A final argument in favor of muscle tension as a relevant feature, according to Galand (1997), is provided by minimal pairs such as [krz] 'plow, aorist' vs. [kkrz] 'plow, imperfective'. Galand (1997) wonders how duration can distinguish these two forms when, with the voiceless stop in the absolute initial position, nothing is perceived before the release. Thus, according to this analysis, only a variation in muscular tension allows to oppose the more powerful explosion of /kk/ to that of /k/ (see Section 4). The same argument is valid, according to Galand (1997), for stops in final position (e.g. [jut] *"he hit"* vs. [jutt] *"he hit him"*). For Galand, tension occurs in all positions, duration only in some of them[8].

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[5]To identify geminates, Galand uses the definition of Dieth (1950: 415) who recognizes in geminates proper two units located on either side of a syllabic boundary, with the mouth pressure showing a drop between the two.

[6]Translation from French of the original text: « *il n'est pas inconcevable […] qu'une énergie musculaire mal dosée ait agi, par excès ou par défaut, sur les mouvements des organes de la parole. Ce ne serait pas le seul cas que de telles bavures auraient été acceptées et pour ainsi dire consacrées par la phonologie.* »

[7]From an aerodynamic point of view, for the vocal cords to vibrate, the difference between the subglottal pressure and the supraglottal pressure must be maintained above a certain threshold. For Galand (1997) the muscular tension decreases this difference.

[8]Galand puts forward another argument of a historical nature. He recalls that Lybic-Berber writing did not note the gemination of consonants and sees this as an indication that the geminate is not felt as a double consonant, so that a single consonant is sufficient to write it. This argument, even if Galand does not dwell on it, should not, in our opinion, constitute a proof in favor of the unitary character of geminate consonants. On the one hand, it is not tenable to construct an argument based on the state of the language more than 2000 years ago. On the other hand, the Libyan alphabet which was strictly consonantal did not note vowels either, is this a proof that Amazigh had no vowels? There are also cases where the

Saib (1977), within the framework of generative phonology, proposes a sequential representation of geminates, while defending that each of the two parts of the geminate is specified by the [+tense] feature. Adopting the autosegmental model, Dell and Elmedlaoui (1997, 2002) considered that the difference between simple and geminate consonants is structural, with geminates as a single bundle of distinctive features linked to two prosodic positions (as in (3b) above). A set of arguments has been proposed by Dell and Elmedlaoui (2002) in favor of this analysis: the fusion of two identical singletons into one geminate consonant thus accounting for the homophony between, for example, /gn-n/ *"they slept"* and /g=nn/ *"put there"*; the fission of some final geminates (e.g. [bdd] *"to stand up"),* which yields [ttbdad] in the imperfective); the similar behavior of geminates and sequences of two consonants with respect to certain phonological processes (see also Saib (1977) and Guerssel (1977)). Other arguments are drawn from syllable structure and morphology (see Dell and Elmedlaoui 2002: 41-55 for details).

As already noted, the discussion of geminate consonants within autosegmental phonology has not been explicit enough about the phonetic features that representation (3b) is supposed to reflect. Ridouane (2010) tested this representational model on experimental grounds, and showed that it accurately accounts for the following observations: (i) The distinction between singletons and geminates is primarily a temporal distinction, including for voiceless stops in utterance-initial position; (ii) When this temporal difference is not acoustically present in the signal, native listeners have more difficulty in distinguishing between singletons and geminates; and (iii) The comparison of different types of geminates (lexical, derived through assimilation, and through concatenation) show that only true geminates exhibit phonetic characteristics that are consistent with the representation (3b).

3. Singletons vs. geminates: acoustic and articulatory attributes

The singleton-geminate contrast in languages other than Tashlhiyt has been examined in a number of different studies, especially in intervocalic position. One consistent aspect shared by geminates in this context is that they are significantly longer than their singleton counterparts. In addition to duration, which can be considered as the primary or the most consistent correlate of geminates, the implementation of gemination may have implications for most if not all of a form's phonetic shape involving additional secondary correlates, such as burst amplitude of the consonant, duration and quality of adjacent vowels, etc. (Lahiri and Hankamer 1988, Idemaru and Guion 2008, Pickett et al. 1999, Payne 2005, Ridouane 2007, Kawahara 2015, Kubozono 2017, see Hamzah et al. 2016 for a review of 39 languages).

3.1. Primary correlate

The primary acoustic correlate of gemination in Tashlhiyt is duration, in the sense that geminates are systematically longer than their singleton counterparts, regardless of segment type and position in the word (Ouakrim 1994, Louali and Puech 1994, Ridouane 2007)[9]. Figure 1 shows acoustic waveforms and spectrograms of the pair /tidi/ *"sweat"* and /tiddi/ *"height"* contrasting /d/ to /dd/ in intervocalic position. As the figure shows, the closure duration of geminate /dd/ is more than twice as long as the closure phase of singleton /d/. Figure 2 illustrates these duration differences in word-final position for the voiceless fricatives /s/ and /ss/ in [ifis] *"hyena"* and [ifiss] *"he is silent"*.

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orthography of a language noted a geminate (doubling of the consonant) where there is in reality only a simple consonant (e.g. in Tamil, Keane 2001).

[9] A primary correlate is understood here as an invariant parameter for all consonants across speakers and phonological contexts, and is thus the primary cue that dominates other cues, which only become tangible in cases where the stimuli are ambiguous (see Lahiri and Hankamer 1988, Pickett et al. 1999, Kawahara 2015).

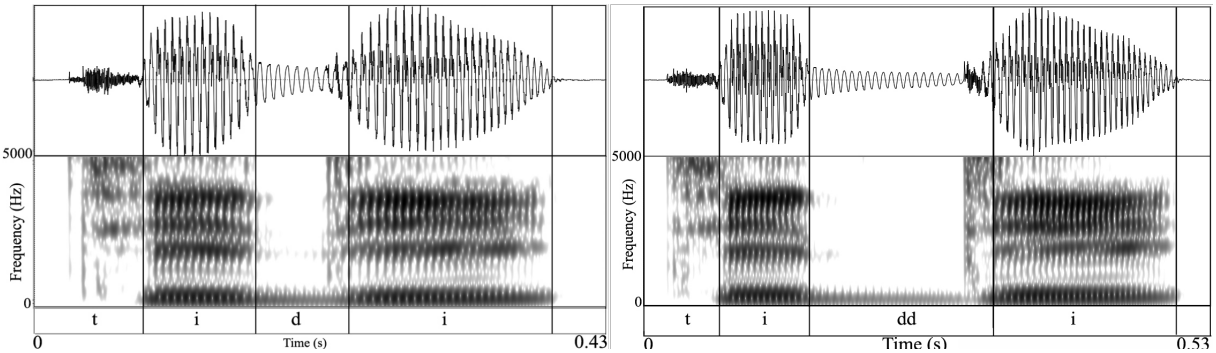

Figure 1. Acoustic waveform and spectrogram of the forms [tidi] *"sweat"* (left) and [tiddi] *"height"* (right), illustrating the durational differences between intervocalic [d] and [dd].

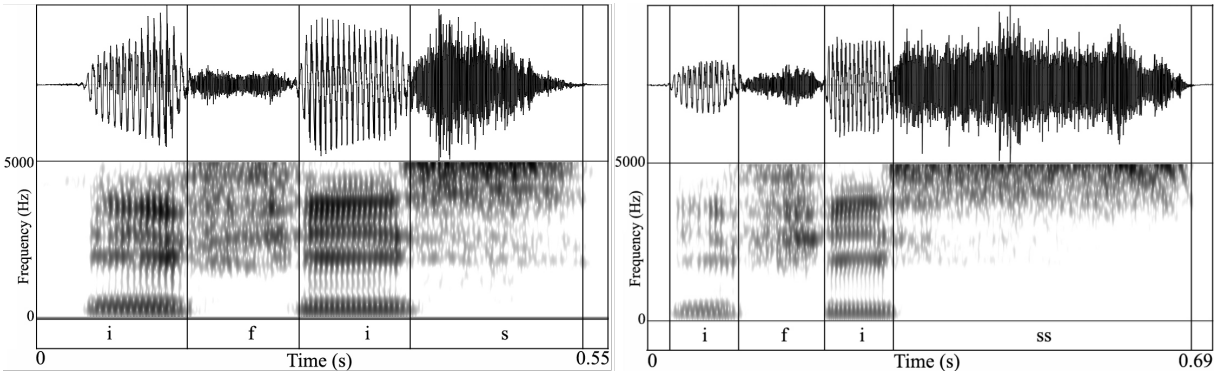

Figure 2. Acoustic waveforms and spectrograms of the forms [ifis] *"hyena"* (left) and [ifiss] *"he is silent"*(right), illustrating the durational differences between [s] and [ss] in word-final position.

The size of duration differences between geminates and singletons in Tashlhiyt vary depending on consonant type and position within the word (Ridouane 2007). Geminate stops are more than twice as long as their singleton counterparts, whereas geminate fricatives are somewhat less than twice as long. Regarding position, the difference between geminates and singletons is greater word-initially and word-finally than word-medially, resulting in a higher geminate-singleton ratio in non-medial positions.

Since closure duration for voiceless stops cannot distinguish singletons and geminates utterance initially (e.g., [tut] *"she hit"* vs [ttut] *"forget it"*), the question arises whether speakers nonetheless use articulatory means to maintain the contrast. Ridouane (2007), using electropalatographic (EPG) data, showed that this was the case: speakers maintain duration differences between singletons and geminates, including for voiceless stops in initial position (see figure 3). At the perceptual level, however, native listeners have difficulties in distinguishing [tut] from [ttut] in this position. I will return to this issue in more detail in section 4.

The EPG data presented in Ridouane (2007) dealt with the temporal dimension of the singleton/geminate distinction. More recently, Ridouane and Hallé (2017) showed that these differences in contact duration could be accompanied by differences in contact area: voiceless and voiced stops, but not fricatives, are produced with larger contact area for geminates than for singletons (see also figure 3)[10]. The observed differences for stops are probably an automatic consequence of the longer contact duration for geminates compared to singletons.

[10]This is consistent with what has been reported for stops in Italian (Payne 2006) and in Cypriot Greek (Armosti 2009).

This suggests that geminate stops would not differ from singletons in terms of the underlying gestural target, but have more time to reach this target. The lack of spatial differences between simple and geminate fricatives is consistent with this analysis. Differences in contact duration for dental fricatives cannot result in contact amplitude differences similar to those for stops because the articulation of these fricatives is more strictly controlled: dental fricatives cannot be produced with a different tongue-palate contact area without risking confusion with the alveopalatal fricatives. In other words, speakers control tongue-tip location more strictly when producing /s/ so that /ʃ/ is not produced instead (Ridouane and Hallé 2017).

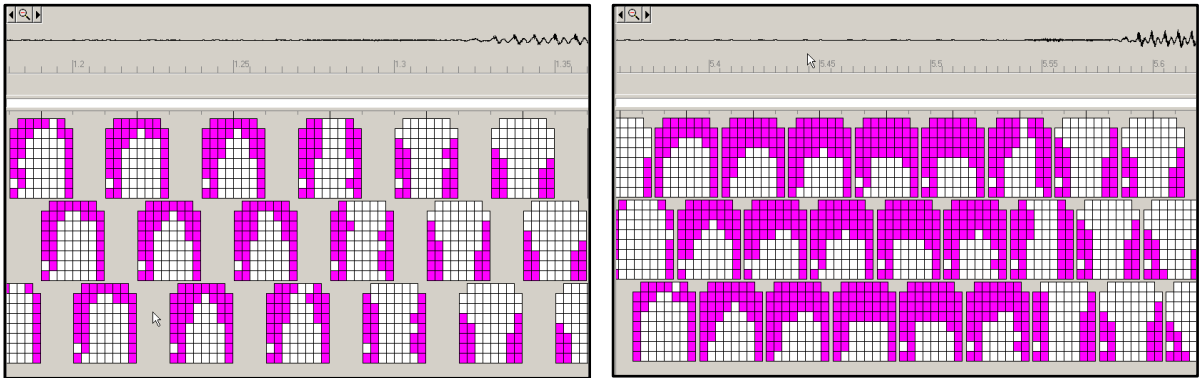

Figure 3. An illustration of durational and spatial differences between utterance-initial singleton /t/ and geminate /tt/ using EPG data. The figure shows number of electrodes activated during the closure phase for the two stops in [tili] *"ewe"* (left) and [ttili] *"have, imp"* (right).

3.2. Secondary correlates

The singleton/geminate contrast in Tashlhiyt is implemented by other correlates in addition to the duration. These correlates can be temporal and non-temporal. Among the temporal parameters, the most important one is the shortening of the duration of the vowel preceding the geminate consonant (Ouakrim 1994, Louali and Puech 1994, Ridouane 2007). This correlate is considered secondary because it is contextually limited, as it is implemented only when the geminate is actually preceded by a vowel. It cannot, for example, be implemented in absolute initial position or in the cases where a word consists of only a geminate (e.g. [kk] *"cross"*)[11].

The shortening of the preceding vowel before geminates, observed in other languages of the world, like Moroccan Arabic (Zeroual 2006), Bengali (Lahiri and Hankamer 1988), Italian (Esposito and Di Benedetto 1999), Hindi (Ohala 2007), and Malayalam (Local and Simpson 1988), has often been attributed to differences in syllabic structure between singletons and geminates: the vowel is longer in an open syllable (V.CV) and shorter in a closed syllable (VC.CV). If this interpretation were correct, then the same vowel shortening would be observed for any VC.CV sequence, whether CC is a geminate or not. This interpretation was tested in Ridouane (2010) for pairs of the type [ikkis] *"he removed"* vs. [iktid] *"he remembers"*. The analyses revealed that vowels remain significantly shorter in a geminate context compared to the non-geminate context. Similarly, the syllabic explanation cannot account for the shortening observed at the end of the word. The vowel in this position is in a closed syllable both in the context of a singleton (VC#) and in the context of a geminate (VCC#), but is only shortened in the geminate context.

Another interpretation for this shortening was put forward by Malécot (1968, 1970) and

[11]A question for future research is whether this shortening can affect any immediately preceding segment, be it a consonant (e.g., is the consonant [f] shorter in [ifssr] 'he explains' than in [ifsr] 'he spreads out'?). To my knowledge this aspect has not been a focus of any previous studies.

adapted by Ouakrim (1994) for Tashlhiyt. According to Malécot (1970), vowel shortening is due to the tendency of speakers to anticipate an important effort and to delay the less important one, so that the more energy a consonant requires the shorter the preceding vowel. The shortening of the vowel would thus be an indication of the greater energy required to produce a geminate. Related to this interpretation, and probably the one most widely held, is that which considers that the length contrast on a geminate segment is enhanced by making the preceding segment shorter (Kluender et al. 1998).

Another temporal parameter that can be considered secondary concerns the duration of the release: voiced geminate stops show longer release duration (30 ms on average) than their singleton counterparts (17 ms on average). This phenomenon, observed also in Bengali (Mikuteit and Reetz 2007) and Finnish (Doty et al. 2007, Engstrand and Krull 1994), is most likely due to the devoicing that affects voiced geminates. No significant difference in VOT duration was observed for voiceless stops. One of the reasons for this is probably related to the fact that singleton and geminate voiceless stops are produced with a similar degree of glottal opening at the time of oral release (see Ridouane, Fuchs and Hoole 2006).

Non-temporal parameters affected by gemination include, but are not limited to, the amplitude of the release, the nature of the closure, and the degree of lenition. Geminate stops tend to be produced with larger amplitude of release than singletons. But this tendency is speaker dependent, having been observed for some speakers but not for all (Ridouane 2007). Similarly, voiceless stops may be produced with incomplete closure. Geminate stops, on the other hand, are systematically produced with total occlusion. The degree of lenition during the holding phase of singleton stops varies according to the voiced/voiceless nature and the place of articulation of the consonant: voiced and velars are more likely to occur without full closure compared to other consonants. Partial devoicing affects voiced geminates, but its importance varies according to the speaker, the place of articulation (more common for velar stops) and the context (more common in final position).

3.3. A contrast with multiple correlates

To sum up, gemination contrast is phonetically implemented by different acoustic correlates in Tashlhiyt. These correlates can be characterized in three ways. Consonant duration can be considered the primary correlate, since the opposition rendered by this attribute is attested in all contexts examined, even for voiceless stops in utterance-initial position. There is no indication that the longer duration of geminates is a consequence of their tense articulation. Instead, it appears that the differences in duration are the result of speakers' intention to maintain a longer duration for geminates (see Louali and Maddieson 1999).

The observed differences in the duration of the release and the degree of devoicing can be seen as concomitant correlates, being consequences of the devoicing that affects these segments due to their longer duration. Vowel shortening and the amplitude of the release, which can be interpreted as manifestations of a tense articulation, are secondary correlates. They are either contextually limited (vowel shortening) or variable across speakers (amplitude of release). These secondary correlates can be considered as enhancing attributes of gemination (Keyser and Stevens 2006, Stevens and Keyser 2010, Clements and Ridouane 2006). They are present to reinforce the primary correlate by adding additional acoustic properties that will increase the perceptual distance between the two phonemic categories. These enhancing correlates can be exploited in cases where the primary correlate is not perceptually recoverable. This is particularly the case for voiceless stops after pause, where listeners cannot detect the differences in closure duration between singletons and geminates (see section 4).

The durational differences between singletons and geminates in Tashlhiyt are accurately captured by structurally treating geminates as two units of duration linked to one melodic

position (as in (3b) above). What is not clear - however - is how to represent the enhancing features? Can the feature [tense] be assigned to the geminate representation as a general effect of phonetic implementation rules? From an articulatory phonology perspective, the tense feature may not be needed, if one views the singleton as essentially an undershot version of the geminate (i.e., both singletons and geminates have the same target specifications, but that the singleton does not get to the target value because of its shorter duration)[12]. A yet different interpretation is suggested by Pierrehumbert's (2002) hybrid exemplar model, according to which memory traces of geminates are hyperarticulated, as only hyperarticulated examples are reliably recognized in their competitions with minimally different competitors. This predicts differential effects on additional correlates depending on whether the geminate is in a dense lexical neighborhood with singleton competitors or not (Pierrehumbert and Clopper 2010).

4. The perception of geminates in Tashlhiyt

The perception of gemination contrasts in Tashlhiyt has been investigated in few studies (Louali and Puech 1994, Ouakrim 1999, Ridouane and Hallé 2017). In intervocalic position, duration was unsurprisingly found to be the most important cue allowing for this contrast to be perceived. Using a forced-choice identification paradigm for the two word pairs [aggar]-[agar] and [ittel]-[itel], Louali and Puech (1994) found that, in addition to the clearly dominant duration cue, other parameters, such as preceding vowel duration and stop release amplitude, might serve as secondary cues.

In initial position, the gemination contrast raises the question of whether durational differences can be perceived for voiceless stops: can speakers of Tashlhiyt perceptually recover the contrast for these segments, even though it conveys no temporal information acoustically? Are native speakers sensitive to attributes other than duration? Ouakrim (1999) was the first to tackle this issue experimentally. He conducted a perceptual study examining the following minimal pair: [tutas] *"she hit for him"* vs. [tttutas][13] *"you forgot for him"*. In a first manipulation, cross-spliced the release portions (corresponding to VOT) of singleton /t/s and geminate /tt/. In a second manipulation, he cross-spliced the vowels following the singleton and geminate stops, leaving the other acoustic parameters unchanged. The aim of these manipulations was to determine whether VOT and/or the following vowel play a significant role in the perception of gemination contrast in this position (since voiceless stop closure duration differences can't be perceived in this position). His results showed a surprising result: the listeners also tended to cross the original meanings of the pair, suggesting that they can reliably perceive the singleton/geminate contrast in the absence of acoustic duration differences.

Ridouane and Hallé (2017) conducted an AXB discrimination test including comparisons of three types of word-initial consonants: voiceless stops (e.g. [tut] vs. [ttut]), voiced stops (e.g. [gar] vs. [ggar]), and voiceless fricatives (e.g. [fit] vs. [ffit]). Their prediction was that native listeners could distinguish [gar] from [ggar] because voicing murmur duration can serve as a reliable acoustic cue, and could be able to discriminate [fit]-[ffit] based on friction noise duration differences. For contrasts such as [tut]-[ttut], however, listeners may give conflicting and unreliable perceptual judgments, given the absence of robust acoustic cues to gemination, in particular closure duration. The results showed that the 23 native speakers/listeners who participated to the experiment consistently performed near ceiling level on word-initial fricatives and voiced stops (> 95%). For word-initial voiceless stops, however, native listeners were far from reaching a comparable level of discrimination performance (less than 62% correct discrimination). These results are shown in figure 4. The accuracy data were

[12] An interpretation suggested by Louis Goldstein.

[13] From underlying /t-ttu-t=as/ '2nd masculine singular-forget-2nd masculine singular=dative 3rd masculine singular'.

corroborated by reaction time (RT) data, also shown in figure 4, with longer RTs for voiceless stops than voiced stops or fricative contrasts by some 180 ms.

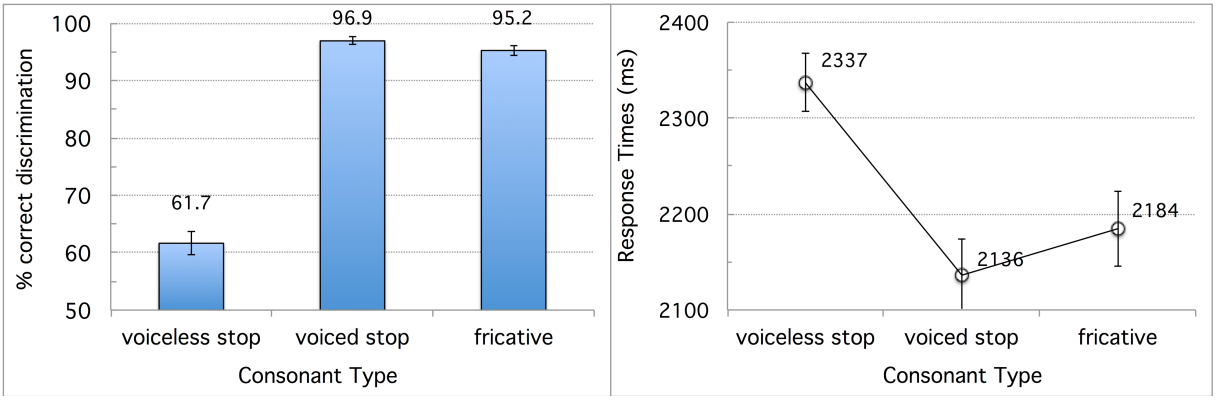

Figure 4. Correct discrimination rate (left) and reaction time (right) for word-initial singleton-geminate contrasts for the three onset consonant types. Error bars represent standard errors (adapted from Ridouane and Hallé 2017).

The inability of listeners to correctly discriminate a voiceless singleton stop from its geminate counterpart in the absolute initial position shows that a phonological contrast, even when it is clearly implemented in the articulation, cannot be perceived in the absence of clear acoustic consequences. I will not discuss the different aspects raised by these results in more detail here. The most important point is what these results tell us about duration as the primary correlate of the opposition between singletons and geminates. Duration is primary because it manifests itself in all contexts where the contrast occurs, and because it constitutes the most important perceptuel cue for native listeners to accurately perceive the contrast at the expected native listening level.

5. Additional issues

Gemination raises other issues not dealt with in detail in this chapter. In this section I will touch upon two issues: the differences between different types of geminates and the fact that an invariant attribute of gemination is relational rather than absolute.

5.1. Lexical vs. derived geminates

As mentioned above, surface geminates in Tashlhiyt can arise from different sources. Tautomorphemic geminates, given by the lexicon, are represented at the underlying level as a single melodic unit related to two prosodic positions (3b). Heteromorphemic geminates can result either from concatenation of two identical consonants separated by a word boundary or from total assimilation. Concatenated geminates are represented at the underlying level as a sequence of two prosodic units each associated with a melodic position. These 'fake' geminates, according to McCarthy (1986), are identical to lexical geminates at the surface level of representation, as a consequence of tier conflation. Geminates resulting from total assimilation result from autosegmental propagation and are also represented as a single melodic unit linked to two prosodic positions (Hayes 1986a). The autosegmental approach thus predicts that the output of the external sandhi is an already established category for lexical contrast. If these analyses are correct, all three types of geminates, regardless of their underlying representations, should be identical at the surface level, represented as a single melodic unit bound to two prosodic positions.

Ridouane (2010) addressed these issues based on acoustic data. The results obtained show that the three types of geminates present the same consonantal durations. This is an argument in favor of an identical representation for these three types of geminates at the prosodic tier

(i.e. associated with two timing units)[14]. Although the three types of geminates may be indistinguishable in terms of absolute consonant duration, vowels were found to be significantly shorter before lexical geminates and assimilated geminates than before concatenated geminates. Another notable difference between the 3 types of geminates concerns the amplitude of release. The measurements show a tendency for lower amplitude of the release for the concatenated geminates, compared to the lexical and assimilated ones.
The fact that geminates resulting from total assimilation are categorically identical to lexical geminates provides further evidence that an external sandhi process - total assimilation - is correctly represented within the framework of a non-linear model, which expresses assimilation not as a modification of a segment, but rather as an autosegmental propagation (see Ladd and Scobbie 2003 for the similar results in Sardinian). This model also provides an adequate representation for concatenated geminates, provided that they are represented at the surface level as two prosodic positions each linked to a melodic position. Obviously, the mere fact of having a sequence of two identical consonants is not sufficient in itself to manifest the expected characteristics of a 'true' geminate. These results indicate a tight relationship between the phonetic characteristics of different types of geminates and their phonological behavior, notably the failure of certain phonological processes to alter true geminates while affecting fake geminates (Hayes 1986b, Elmedlaoui 1993). For example, in Tashlhiyt spoken in Western High Atlas, lexical geminates never spirantize. Geminates resulting from total assimilation also resist the application of this rule, while geminates resulting from concatenation do spirantize (Ridouane 2010).

5.2. Gemination and speech rate: a search for invariance

Various studies have shown that speech rate affects singletons and geminates differently (Pind 1995, Picket et al. 1999, Hirata and Whiton 2005). The research question was whether there exists an invariant acoustic correlate that can transcend these speech rates. The findings suggest that this invariant measure is relational. Pickett et al. (1999), based on Italian, showed that the ratio between consonant duration and preceding vowel duration (C/V) allowed discriminating between singletons and geminates both within and across speaking rates. Hirata and Whiton (2005), based on Japanese, also showed that relational measures classified accurately singletons and geminates, with the highest accuracy for consonant/word (C/W) ratio (see also Idemaru and Guion 2008).
In a recent preliminary study, Hermes et al. (2021) examined whether it was possible to provide an invariant acoustic attribute of gemination contrast in Tashlhiyt that is also independent from speech rate. The study compares data from four typologically unrelated languages, which includes Finnish, Italian and Japanese, in addition to Tashlhiyt. One speaker from each language was recorded producing the pair /ima/ and /imma/ embedded in a carrier sentence, and repeated 640 times[15]. The acoustic parameters measured included both absolute and relational ones, such as preceding vowel duration, consonant duration, following vowel duration, C/V ratio and C/W ratio.

[14]The same absence of consonant duration differences between true and fake geminates was obtained for Estonian (Lehiste, Morton, and Tatham 1973), Levantine Arabic (Miller 1987), and Bengali (Lahiri and Hankamer 1988).
[15]To elicit variation in speech rate, the authors used a motion-based cue for rate. The cue was a red box that moved across the screen over a range of rates (ranging in 20 steps from minimum cue duration of 0.75s to maximum cue duration of 3s).

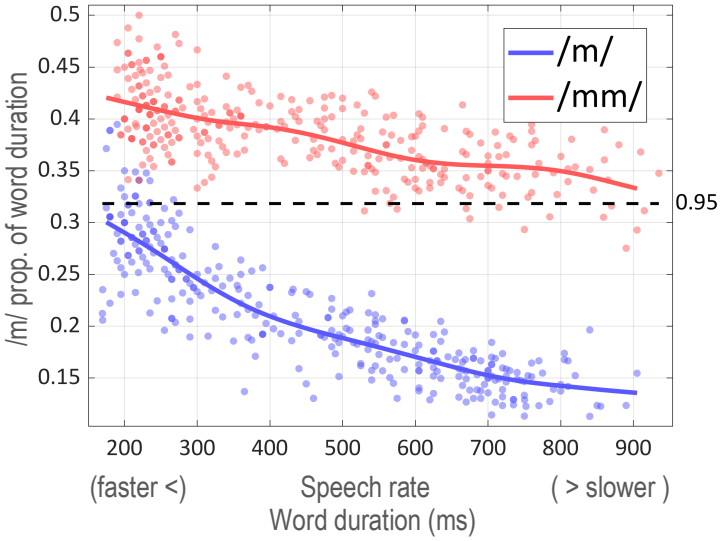

Figure 5. Ratio of /m/ and /mm/ to word duration plotted against word duration. Dashed line represents optimal boundary computed as 0.32.

Results showed that durations of [mm] and [m] change with rate in Tashlhiyt as well as in other languages, with geminate consonants increasing more as rate slows. When speech rate is slower, the differences in absolute durations between singletons and geminates are further enhanced with an increase in geminate durations. Rate effects on the preceding vowel were smaller before [mm] than [m], while the interaction with the following vowel was similar between singletons and geminates. This shows that gemination affects the preceding vowel duration more strongly than the following vowel duration. Importantly, despite large overlap of singleton/geminate durations at fast rates, a relational measure reliably distinguishes between the two categories, and thus could form the basis for a speech rate-independent attribute of gemination. As figure 5 shows, the C/W ratio allowed to accurately classify the singleton and geminate tokens in Tashlhiyt, with a boundary at 32% and a classification accuracy of 95%. This means that if the duration of the labial nasal is less than 32% of the word duration, the word almost certainly contains a singleton /m/, and if it is more than 32% of the word duration, the word almost certainly contains a geminate /mm/. This boundary ratio shows a remarkable similarity between the four languages (varying from 29% to 37%), and provides additional evidence that the invariant acoustic attribute of consonant gemination is relational rather than absolute.

6. Conclusion

This chapter was designed as a basic overview into the nature of gemination contrast and how it is phonetically implemented and perceived in Tashlhiyt. From a phonological point of view, geminates in this language are best represented within an Autosegmental theory, as sequences of two timing positions linked to a single melodic position. Both production and perception data allowed to test a set of predictions that follow from this phonological representation. In particular, the distinction between singletons and geminates is mainly a temporal one, and this is true for all obstruents in all positions, including voiceless stops after pause. In the absence of this temporal dimension, the distinction between singletons and geminates is perceptually much weaker, with native listeners unable to adequately recover the contrast for post-pausal voiceless stops in the absence of enhancing features. An additional argument is that the autosegmental analysis provides an adequate representation for different types of geminates and accounts for the fact that geminates resulting from total assimilation are categorically identical to lexical geminates.

The review of the current state of research on gemination in Tashlhiyt shows that this issue has been examined both from theoretical and empirical perspectives. Much work is still needed, however, to fully understand the behavior of these segments. Some directions for further studies that are worth exploring in the near future include, but are not limited to the following: (i) The acquisition of gemination contrast by natives, (ii) The articulatory characteristics of Tashlhiyt geminates. Compared to acoustic and perception studies of Tashlhiyt geminates, there are relatively fewer studies on the articulation of these segments, (iii) The syllabic status of initial and final geminates, which some times behave as single segments and sometimes as a sequence of two consonants, and (iv) The processing of consonant duration.

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