Schwa elements in Tashlhiyt word-initial clusters

RACHID RIDOUANE and CÉCILE FOUGERON

Laboratoire de Phonétique et Phonologie (UMR 7018, CNRS/Sorbonne-Nouvelle)

Abstract

This paper deals with schwa elements that sometimes occur between consonants in Tashlhiyt Berber and seeks to determine where they come from. Based on acoustic data on word-initial C_1C_2 clusters, we examine how laryngeal specifications, manner of articulation and ordering of the place of articulation of the consonants in the cluster may govern their distribution and their durational characteristics. Results show that their occurrence in the acoustics is only possible in specific consonantal contexts, and under certain conditions of gestural coordination. Specifically, two conditions should be met for these schwas to surface. First, at least one of the consonants in the sequence should be voiced, as they never occur in word initial voiceless clusters. Second, the vocal tract has to be sufficiently open during the transition from one consonant configuration to the other. They are therefore most frequent at the release of the first consonant of stop-stop clusters and in sequences with minimal overlap. In addition, schwas are found to have variable durations depending on speaker and cluster type, but the durations of clusters with or without them are essentially indistinguishable. Taken together, these results suggest that schwa elements in Tashlhiyt emerge as a consequence of factors linked to phonetic implementation.

1. Introduction

Tashlhiyt is known to have particularly long consonantal sequences and vowel-less words. The form /t-bdg/ 'it is wet', for example, is composed underlyingly of consonants only.[1] It may surface, however, with three vocalic, schwa-like, elements at the acoustic level, as shown in Figure 1 (Hereafter, we will transcribe these elements using the symbol [@]).

Where do these vocalic elements come from? This question has important theoretical implications and bears crucially on the syllable structure of Tashlhiyt, all the more so because the contexts where these elements can potentially occur are extremely frequent in the language. Arguing that they are segmental vowels implies that the so-called consonant-only syllables are in fact canonical syllables with

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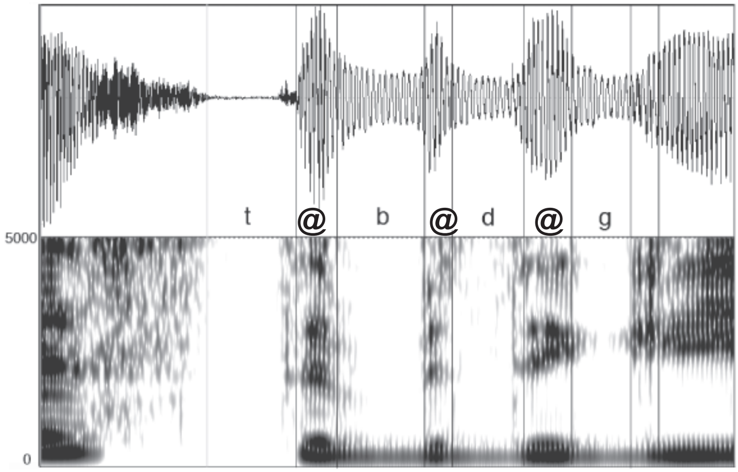

Figure 1. *Acoustic waveform and spectrogram displaying three schwa elements within the consonant-only word* /t-bdg/ *'it is wet', embedded in the carrier sentence* inna jas . . . jat twalt *'he told him . . . once'.*

a vocalic nucleus (we call this the *Schwa-nucleus theory*). If one argues, on the other hand, that these vocalic elements have no structural relevance and cannot act as syllable peaks, this implies that a form like /t-bdg/ has obstruent-only syllables with stops acting as nuclei (we call this the *Noschwa-nucleus theory*).[2] The former position has been defended by Coleman (1996, 2001), in his analysis of the variety of Tashlhiyt spoken in Agadir. According to him, these elements are the phonetic realizations of empty nuclei. The latter analysis was first proposed by Dell and Elmedlaoui (1985, 2002; see also Boukous 1987; Prince and Smolensky 1993; Ridouane 2008), in their analysis of the variety of Tashlhiyt spoken in Imdlawn Valley. According to them these vocalic elements are transitional vocoids which do not play any role in syllable structure.

Although various arguments have been presented by the proponents of the two positions (some of these are outlined in Section 1.2), our knowledge of the exact nature of these schwa elements is still incomplete. In the present paper we provide new data bearing on the factors that may govern their distribution and their durational characteristics in word-initial CC clusters.

In the remainder of this introduction, we will discuss the phonotactics of Tashlhiyt word-initial clusters and then briefly review some previous reports on the nature of schwa and its role within the syllable.

1.1. *The phonotactics of Tashlhiyt word-initial clusters*

Tashlhiyt is a Berber language spoken in Morocco by about 5 to 6 million speakers. The language has 64 consonants, four glides, and three phonemic vowels /a, i, u/,

Table 1. *Tashlhiyt phoneme inventory.*

labial	dental	palatoalveolar	velar	uvular	aryepiglottal	glottal
	t tˤ		k kʷ	q qʷ		
	tt ttˤ		kk kkʷ	qq qqʷ		
	d dˤ		g gʷ			
	dd ddˤ		gg ggʷ			
	n nˤ					
	nn nnˤ					
f	s sˤ	ʃ ʃˤ		χ χʷ	ʜ	h
ff	ss ssˤ	ʃʃ ʃʃˤ		χχ χχʷ	ʜʜ	hh
	z zˤ	ʒ ʒˤ		ʁ ʁʷ	ʕ	
	zz zzˤ	ʒʒ ʒʒˤ		ʁʁ ʁʁʷ	ʕʕ	
w	l lˤ	r rˤ	j			
ww	ll llˤ	rr rrˤ	jj			
u			i		a	

as shown in Table 1. Any of the three underlying vowels may occur word initially, medially, or finally. Unlike vowels, all consonants and glides come in pairs (singleton and geminate), though some geminate consonants are rather rare (e.g., /ʃʃˤ, ʒʒˤ, nnˤ, /ʜʜ, ʕʕ/ and hh/). Geminate consonants may occur at various different positions within a word: they can contrast with singletons in intervocalic position as well as in absolute initial and final positions, and can be preceded or followed by one or more consonants (see Ridouane 2007).

In addition to geminates, Tashlhiyt allows other types of consonant sequences. We limit ourselves to word-initial obstruent C_1C_2 sequences, since this type of clusters is the focus of this study, and briefly show how they phonotactically pattern in terms of manner of articulation, place of articulation, and voicing specifications (see Applegate [1958], Boukous [1987], and Dell and Elmedlaoui [1996] for a detailed description of other types of consonant sequences of Tashlhiyt).

In terms of manner of articulation, the four possible fricative/stop combinations are attested in the initial position of a monomorphemic word, as shown in (1):

(1)	stop-fricative:	/bsi/	'to melt'
	stop-stop:	/kdˤu/	'to smell'
	fricative-stop:	/zdi/	'to fasten'
	fricative-fricative:	/χsi/	'to choke'

In terms of voicing specifications, also illustrated in (1), all the four possible combinations of voicing within a monomorphemic word-initial cluster are attested: [voiced, voiceless], [voiceless, voiced], [voiced, voiced], and [voiceless, voiceless].

While the combination of consonants in terms of voicing and manner of articulation is quite permissive, their combination in terms of place of articulation is strictly constrained (see Boukous [1987] for a detailed presentation). For example, no monomorphemic word may contain two adjacent labial obstruents [*bf, *fb], two back obstruents [*kq, *qg, *χʜ, etc.],[3] or two strident fricatives [*sʃ, *ʒz].

With the exception of three items, cited in Boukous (1987), monomorphemic words may not contain a sequence of two dental stops, even if they differ in voicing or dorso-pharyngealization. But two consonants sharing the same place of articulation may be adjacent in heteromorphemic words. Through prefix concatenation, the sequence /t-t/ in /t-tabʕa/ '3fem. sg, follow' for example, may either be realized as one geminate stop [tt], or the oral closure of the first stop may be released before that the second stop is formed [t't]. In heterorganic obstruent C_1C_2 clusters, all combinations of different places of articulation are possible, and the release of C_1 is obligatory.

As some of the items in (2) also show, Tashlhiyt allows monomorphemic word-initial clusters that violate traditional principles of sonority well-formedness. Words may begin with consonants having the same sonority value (e.g., [χsi] 'to choke', [kti] 'to remember'), or sonority reversals (e.g., [zdi] 'to fasten', [rku] 'to dirty'), in addition to more common obstruent-sonorant clusters ([gnu] 'to sew', [kru] 'to rent'). Related to this issue is the syllable structure of Tashlhiyt.

1.2. *Tashlhiyt syllable structure and the nature of schwa*

In addition to the typologically common vowel-nucleus syllables V, CV, VC, and CVC, Tashlhiyt is claimed to have consonant-only syllables C, CC, CC, and CCC, where even a voiceless stop can be nucleus (e.g., [n.gn] 'we slept', [tk.ti] 'she remembered'). Various arguments, both external and internal, have been put forward as evidence for this analysis. The external evidence is derived from judgments about well-formedness in versification (Dell and Elmedlaoui 2002). The internal evidence includes insights into various morphological regularities captured by assuming the proposed syllabification of consonant sequences (see Dell and Elmedlaoui [2002: 115–134] for a detailed discussion of these morphological regularities).

The most disputed component of this analysis concerns the status of the schwa elements that are sometimes present within some consonantal clusters. According to the *Noschwa-nucleus theory*, these schwas are mere transitional vocoids, the distribution of which depends on the phonetic make-up of the adjacent consonants. Specifically, Dell and Elmedlaoui (2002), based on auditory inspection of Elmedlaoui's productions, argue that schwa occurs only adjacent to a voiced consonant within a heterorganic cluster. However, the authors did not report any experimental phonetic data to back up these judgments. In addition, their auditory observations of heterorganic clusters were primarily based on stop-stop consonants, as they found that schwas within sequences containing a fricative were rather hard to perceive. Ridouane (2008) provided phonetic data on words composed of voiceless obstruents only (such as [tkkststt] 'you took it off, fem.'). His results showed that voiced schwas are extremely rare within such words (98 out of 432 repetitions) and occur mainly in utterance final position (84 out of 98). Internal schwas were interpreted as due to the influence of Moroccan Arabic, a language which has epenthetic schwas. Utterance final schwas were tentatively analysed as cues to mark a phrase boundary.

Arguing that CVC syllables (where V = schwa) are less marked than CC syllables, some authors have analysed Tashlhiyt syllabic consonants as sequences of schwa + consonant (Coleman 2001; Puech and Louali 1999). According to Coleman, schwa, which is interpreted as the phonetic realization of an empty nucleus, is expected to occur in any syllable nucleus that is not filled by one of the lexical vowels /a, i, u/, suggesting that it is not conditioned by phonetic environment.[4] Among the arguments presented by Coleman (2001) in support of this analysis, his acoustic measurements are of relevance here. His data consisted of recordings of the Tashlhiyt forms in Dell and Elmedlaoui (1985), produced by Elmedlaoui and repeated two to four times. The author used signal detection theory (Macmillan and Creelman 1991) to compare the goodness-of-fit between the observed distribution of schwas in Elmedlaoui's speech and their expected occurrence according both to the Schwa-nucleus hypothesis and to the Noschwa-nucleus hypothesis. The results he obtained showed that schwas occurred in 40% of the subject's realisations. The overall goodness-of-fit, as indicated by d′ statistics, showed that the Schwa-nucleus model is only slightly better at predicting the occurrence of schwa vowels (d′ = 4.74 as compared to d′ = 4.34). Nonetheless, some arguments in favor of this analysis can be found in the observation of some renditions which seem problematic for the Noschwa-nucleus model. First, one of the items of his corpus, the word [nʃfat] 'skin! (v. pl.)', was produced once by the speaker with an initial schwa vowel (i.e., [@nʃfat]). According to Coleman, this is unproblematic if /n/ is a syllable coda preceded by an empty nucleus (instead of a syllable nucleus in Dell and Elmedlaoui's account). Second, the form /t-mzʜ/ 'she jested', was produced with a schwa in word-final position. This schwa cannot be considered as a transition between consonants, since it occurs in word-final position preceded by a voiceless consonant. According to Coleman, this occurrence is consistent with the analysis of stem-final /ʜ/ as a syllable onset followed by an underspecified nucleus, the voicing of this schwa arising from its being a syllable nucleus (i.e., [t@mz.ʜ@]). Coleman also provided one example of a voiceless cluster containing a voiced schwa element ([lq@stt] 'the story'). This case is problematic for the Noschwa-nucleus analysis since if schwas were intrusive elements which copy over voiced consonants only, then this voiceless sequence would normally be expected to surface as genuinely non-vocalic, lacking schwa.[5] The acoustic data presented by Coleman are very limited, however, and concern only the productions of one subject. Moreover, the data set included a variety of word structures which are not balanced enough to apprehend the factors conditioning the occurrence of schwa. A critical question is thus far from being clearly settled: What are the factors which condition the distribution of these elements in Tashlhiyt?

In this article, we present new data in order to help answer this question. Based on controlled multi-speaker acoustic data on obstruent-obstruent word-initial clusters, we seek to determine how the laryngeal specification, the manner of articula-

Table 2. *List of the 31 word-initial clusters presented according to the laryngeal specification of C_1 and C_2 ('vd' = voiced and 'vl' = voiceless), the ordering of their place of articulation ('fr' = front and 'bk' = back), and their manner of articulation ('Fric' = fricative). The empty cell is due to a lack of actual Tashlhiyt word with the relevant structure.*

	[vd, vd]		[vl, vd]		[vd, vl]		[vl, vl]	
	fr-to-bk	bk-to-fr	fr-to-bk	bk-to-fr	fr-to-bk	bk-to-fr	fr-to-bk	bk-to-fr
Stop-Stop	bdiʁ	gdˤiʁ	tgim	kdˤiʁ	bqiʁ	gtinn	tqijs	ktiʁ
Stop-Fric	bzˤiz	gziʁ	tˤʁiʁ	---	bsiʁ	ddfiʃ	tʃib	ksiʁ
Fric-Stop	zgiʁ	zbiʁ	sgin	ʜbiʁ	zkiʁ	ʕtiq	fkiʁ	χtiʁ
Fric-Fric	zzʁur	ʁziʁ	sʁiʁ	ʁzit	ʒʒʜid	ʕfiʁ	fsiʁ	χsiʁ

tion and the ordering of the place of articulation of the consonants in the sequence affect both the distribution and the duration of Tashlhiyt schwa elements.

2. Method

2.1. *Material and subjects*

The thirty-one meaningful items of the form #C_1C_2VC presented in Table 2 were recorded by 5 native speakers of the Agadir variety of Tashlhiyt. The corpus was designed in order to vary the nature of the consonants in the initial C_1C_2 cluster, in terms of:

- Their laryngeal specifications, with 4 conditions: [voiced, voiced], [voiced, voiceless], [voiceless, voiced], and [voiceless, voiceless].
- Their manner of articulation, with 4 conditions: [stop, stop], [fricative, fricative], [stop, fricative], and [fricative, stop];
- The ordering of their place of articulation, with 2 conditions: [back-to-front] and [front-to-back].

The morphological structure of the test items as well as their meanings is given in the appendix. 26 out of the 31 C_1C_2 clusters are monomorphemic. In the five heteromorphemic clusters, the first or the second consonant is either a clitic or a direct object. Three items contained initial geminates due to a lack of actual Tashlhiyt words with initial singletons in the relevant contexts. The possible impact of these geminates on the results obtained will be addressed in the presentation of the results by systematically reporting whether the tendencies hold with and without these three test items. All the obstruent sequences are followed by the vowel /i/, except for one item where it is followed by the vowel /u/ (i.e., /zzʁur/).[6] The items, all constituting a single phonological word, were embedded in the carrier sentence *inna . . . jat twalt* 'he said . . . once'. Sentences were randomized in a list and printed out in roman orthography, familiar to the speakers. Each sentence was read five times by the participants.

Table 3. *List of 10 additional items comparing $C_1(@)C_2$ clusters to C_1VC_2 sequences.*

$C_1(@)C_2$	*Gloss*	C_1VC_2	*Gloss*
tgnitas	'you sew for him'	tignijad	'this sewing'
tbditas	'you started for him'	tibdijad	'this starting'
trbitas	'you carried for him'	tirbitad	'this girl'
tʁritas	'you called him'	tiʁrijad	'this study'
tmlitas	'you showed him'	timlijad	'this designation'

In order to compare the effect of schwa on the total duration of a cluster with that of a full vowel, we recorded an additional corpus, displayed in Table 3, where word initial C_1C_2 clusters were compared to C_1VC_2 sequences. The C_1C_2 clusters were selected to induce the occurrence of a schwa-like element (based on our prior analysis of the data in Table 3) and the high vowel /i/ was chosen as the nucleus of the C_1VC_2 forms because it is intrinsically short. Each item is composed of three syllables; the first syllable being the focus of our measurements. The items were read six times within the carrier sentence '*inna* . . .' 'he said . . .', where the intonational peak falls on the last syllable, the first syllable being unaccented.

Recordings were made in two different sessions. The first recording included clusters containing at least one voiced consonant (columns 2 to 7 in Table 2) by two females (NA and SO) and three males (AB, CH, and RR[7]). The second recording included voiceless clusters (columns 8 and 9 in Table 2) by NA, SO and RR, and two other males (EL, HA)[8] and the corpus presented in Table 3 by SO, RR, EL, and HA. The age of the subjects ranged from 28 to 46 (mean = 36).

Recordings were made in a soundproof booth at the Laboratoire de Phonétique et Phonologie in Paris for AB, CH, SO, RR, and in a quiet room for EL, HA, NA. Before recording began, participants were asked to read the list in front of the experimenter (the first author) to ensure that they were familiar with all the items. The participants were asked to repeat the phrase if it was not pronounced correctly. A total of 1014 tokens is included in the analyses.[9]

2.2. *Analysis*

Different measurements were taken from the acoustic records for each sequence:

1. Number of occurrences of [@] between C_1 and C_2
2. Absolute duration of [@] (if present)
3. Duration of the [$C_1(@)C_2$] and [C_1VC_2] sequences measured as the temporal interval between the offset of the preceding vowel and the onset of the following one.
4. Relative duration of [@] expressed as a percentage of the duration of the [$C_1@C_2$] sequence.

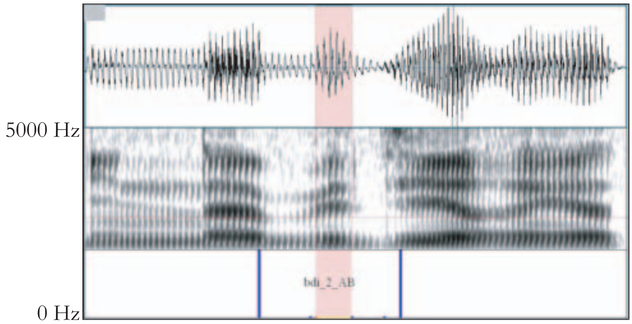

Figure 2. *Sequence [innabdiʁja] produced by speaker AB with a clear schwa between C_1 and C_2 in the /bd/ cluster as shown by the increase of energy in the signal and rather long interval with formant structure in the spectrogram.*

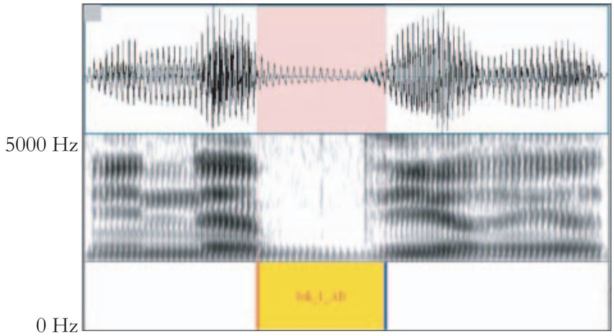

Figure 3. *Sequence [inanbdiʁja] produced by speaker AB. No schwa is observed within the /bd/ cluster.*

Determining whether there was a schwa within the C_1C_2 cluster was not always straightforward. The labelling of the data was done in two steps. A naïve (native) annotator did a first pass on the data to label all the non-ambiguous cases and mark the ambiguous cases. These latter cases were re-examined by the two authors who tried to force the classification (absent/present) based on the criteria described below. Decisions were made based on a combination of cues. In clusters containing at least one voiced consonant, the presence of periodic vibration alone was not a sufficient criterion for the presence of a schwa element.[10] We rather labelled as [@] any interval between the two consonants presenting some periodic vibrations accompanied by a local increase in the signal energy at C_1 release, and/or an interval after C_1 release with formant structure or some energy in the F2/F3 region characteristic of vowels. In the example presented in Figure 2, the presence of a schwa was easily determined based on the clear increase/decrease of signal amplitude and a rather long interval with formant structure within the C_1C_2 interval.

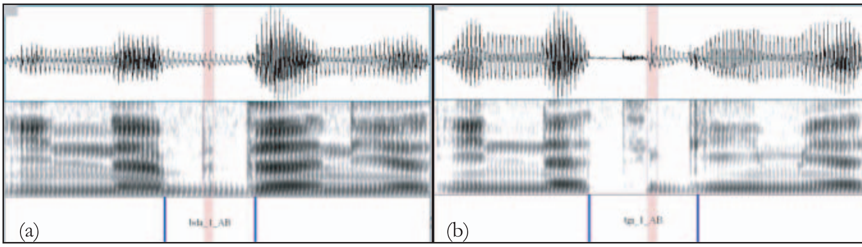

Figure 4. *Productions by AB of the sequences [inabdanja] (left) and [inatgimja] (right) illustrating cases where deciding on the presence or absence of a schwa within the clusters /bd/ or /tg/ was not straightforward (see text). Spectrograms show 0–5000 Hz.*

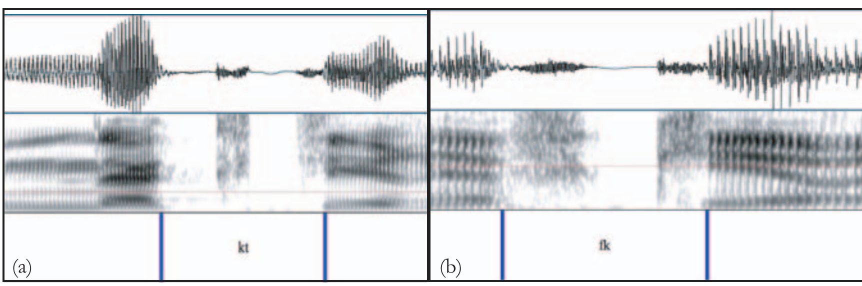

Figure 5. *Acoustic waveform and spectrogram of [innaktiʁ] 'I remember', as realised by HA (left), and [innafkiʁ], as realized by EL (right), showing the absence of a schwa element within the voiceless clusters.*

Figure 3, on the other hand, illustrates a case where the /bd/ cluster is clearly produced without a [@]. The examples presented in Figure 4 illustrate more complicated cases. In the left panel, the presence of [@] was determined based on the small interval (2–3 periods) showing a slight increase of amplitude in the continuous periodic signal and the formant structure around 1500 and 2400 Hz. In the right panel, the presence of [@] was determined based on the short increase of energy at the onset of voicing in the signal after the release noise of /t/ and the short concentration of energy around 2100 Hz.

3. Results

The results presented here will mainly concern the occurrence of schwa elements and their duration in the clusters containing at least one voiced consonant. The case of [voiceless, voiceless] sequences is dealt with rapidly: no schwa element is observed in these data. All these initial clusters are thus genuinely voiceless and vowel-less. Illustration of two such productions is given in Figure 5.

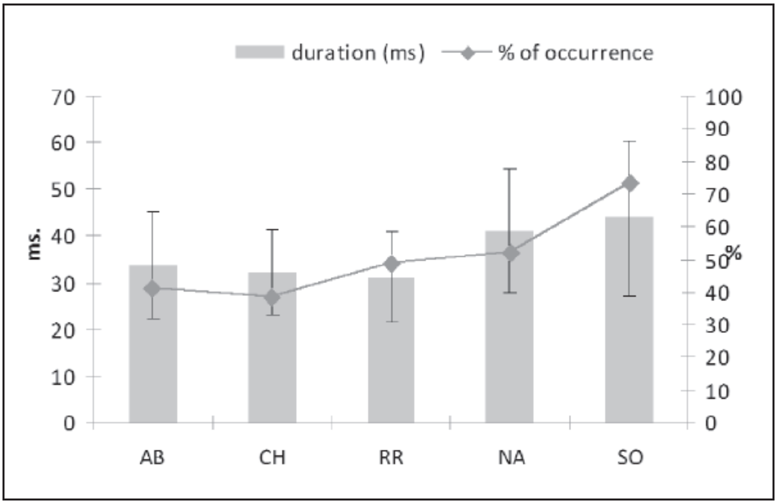

Figure 6. *Percentage of occurrence (curve, right axis) and duration (bars, left axis) of the schwas found between C_1 and C_2 per speaker in the clusters containing at least one voiced consonant.*

3.1. *Description of the schwas occurring in the C_1C_2 clusters containing at least one voiced consonant*

The occurrence of schwas in the acoustic records of our speakers is not rare: 291 [@]'s are observed, representing 51% of the 574 tokens of the C_1C_2 containing at least one voiced consonant. As shown in Figure 6, the frequency of occurrence varies depending on the speaker ($\chi^2[4, 574] = 34.5$, $p < .0001$), ranging from 38% for CH to 73% for SO, with the two female speakers (SO and NA) having the highest frequencies of occurrence.

The duration of [@] also varies according to speakers ($F[4, 286] = 12.3$, $p < .0001$), with the two female speakers (NA, SO) having significantly longer [@]s than the male speakers (AB, CH, RR). The duration of schwa ranges from 31 to 44 ms. However, this range of variation disappears when [@] duration is computed relative to the duration of the whole C_1C_2 sequence: the vocalic portion of the signal represents 18 to 19% of the sequence for all the five speakers.

3.2. *Duration of the [C_1(@)C_2] sequence*

If schwas were vowel segments, one might expect to see an increased duration in the sequence where they occur. To test this we first compared the duration of the C_1C_2 sequences according to the presence or absence of [@]. Results, illustrated in Figure 7, show that the C_1C_2 sequences have the same duration whether there is a

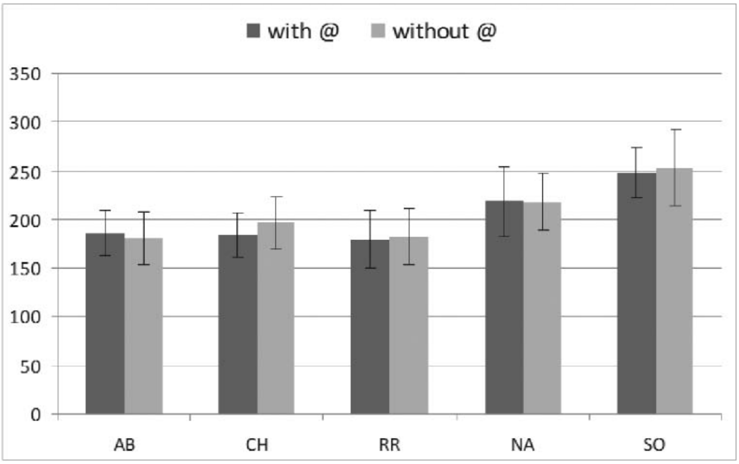

Figure 7. *Duration of the C_1C_2 sequences according to the presence or absence of [@] between C_1 and C_2.*

[@] in the sequence (mean 203 ms) or not (mean 206 ms) ($F[1, 564] = 1.2$, $p = 0.2$), and no interaction is found with the speakers ($F[4, 564] = 1.4$, $p = 0.2$). The same result is obtained with data excluding the three sequences with geminates (197 ms and 201 ms, respectively) ($F[1, 489] = 2.7$, $p = 0.09$).

To further test for the effect of [@] on the duration of the cluster where it occurs, we compared sequences containing a schwa with sequences containing a full vowel /i/ (see the corpus in Table 3). Out of the 120 C_1C_2 tokens, 101 contain a schwa element and 19 surface with no schwa. Because of the limited number of sequences without a schwa, analysis is limited to C@C clusters as compared to CVC. The results, illustrated in Figure 8, show that for all speakers, the clusters containing a schwa (mean 182) have a shorter duration than sequences containing a vowel /i/ (mean 239 ms) ($F[1, 219] = 796.3$, $p < .0001$). Thus, while [C@C] sequences have the same duration as [CC] sequences, they are significantly shorter than [CVC] sequences.

3.3. *Distribution of the schwas according to cluster type*

In this section we test whether the distribution of [@] varies according to the laryngeal specifications of the consonants, their manner of articulation, and the ordering of their place of articulation within the sequence.

3.3.1. *Laryngeal specifications.* Figure 9 presents the distribution of [@] according to the laryngeal specifications in the sequence, as well as their relative duration expressed as a percentage of the C1C2 sequence. As reported above, [@]

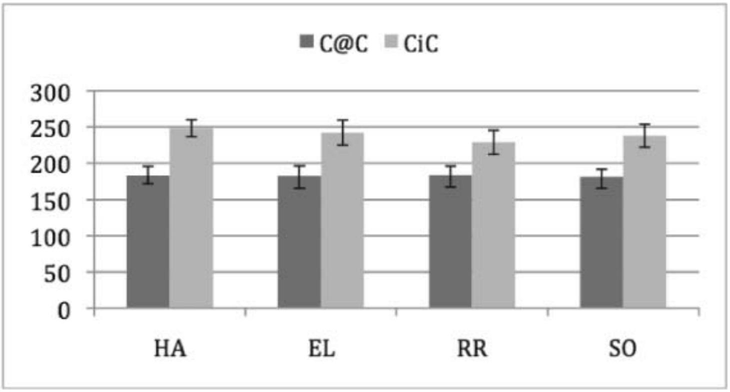

Figure 8. *Duration of C@C and CiC sequences by speaker.*

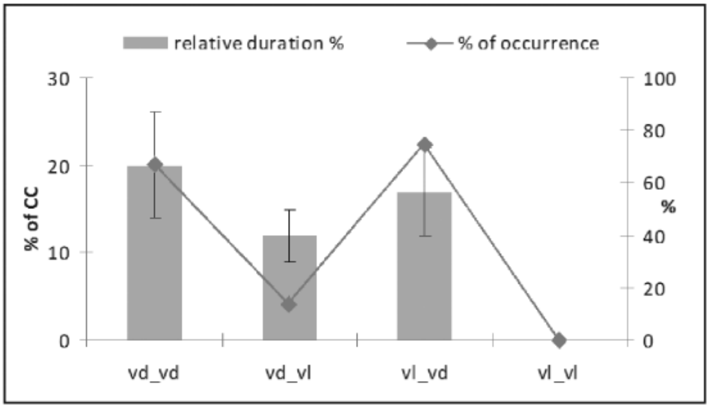

Figure 9. *Percentage of occurrence (curve, right axis) and relative duration (bars, left axis) of the schwas according to the laryngeal specification of the consonants in the cluster (vd = voiced, vl = voiceless).*

is never observed within the word-initial [voiceless, voiceless] clusters. We report this result in Figure 9 as well for the sake of completeness.

For the three conditions containing at least one voiced consonant, the laryngeal specifications in the cluster are found to condition the distribution of [@] (χ^2[2, 574] = 171.7, $p < .0001$). Schwas are the most frequent in [voiceless, voiced] sequences (74%) and in sequences formed by two voiced consonants (67%), while they occur in only 14% of the [voiced, voiceless] sequences. The duration of [@] is also a function of the laryngeal specifications of the consonants in the cluster (F[2, 289] = 32.3, $p < .0001$). [@]s are longer in [voiced, voiced] clusters, than in [voiceless, voiced], which are in turn longer than in [voiced, voiceless] (all pair-

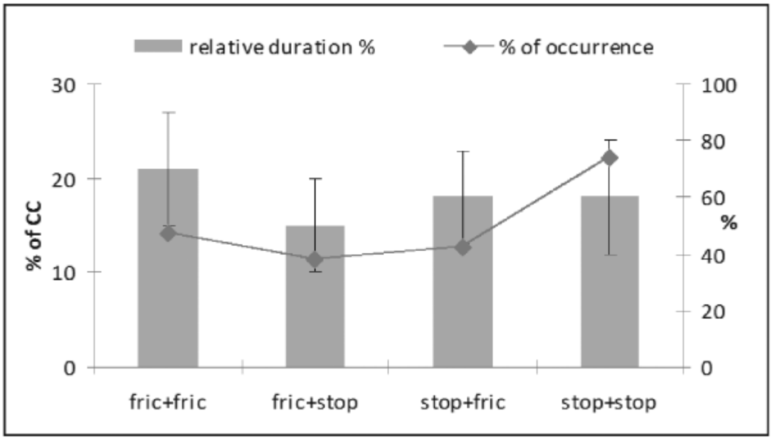

Figure 10. *Percentage of occurrence (curve, right axis) and relative duration (bars, left axis) of the schwas according to manner of articulation of the consonants in the sequence (fric = fricative).*

wise comparisons are significant at $p < .0001$). Data without geminates also display the same three-way distinction ($F[2, 270] = 37.3$; $p < .0001$).

3.3.2. *Manner of articulation.* The manner of articulation of C_1 and C_2 in the cluster is also found to condition the distribution of [@] ($\chi^2[3, 574] = 46.8$, $p < .0001$). Schwas, as illustrated in Figure 10, are more frequent in stop + stop clusters where they are observed in 74% of the tokens. In sequences involving a fricative, [@] occurs in less than half of the tokens (38% for fricative + stop, 42% for stop + fricative, and 47% in fricative + fricative clusters).

The relative duration of [@] also varies according to the manner of articulation of the consonants ($F(3, 287) = 9.2$, $p < .0001$). A three-way distinction is made with fricative + fricative having the longest [@], fricative + stop sequences having the shortest, and stop + stop and stop + fricative sequences having [@] of intermediate duration. Note that the longest schwas are found in the longest type of sequence: fricative + fricative sequences are 226 ms in average, while the other three sequences have similar durations (201–205 ms). Analyses conducted on the data without the geminates show the same effect of manner of articulation ($F[3, 269] = 13.3$, $p < .0001$).

3.3.3. *Order of place of articulation.* In the preceding section we have seen that 74% of the stop-stop clusters are produced with a schwa. For a schwa element to surface acoustically, the vocal tract has to be open enough at the transition from one stop to the next. As shown in Fougeron and Ridouane (2008a), based on electropalatographic data, no vocalic element is acoustically present within homorganic sequences. In items of the type [tntltnt] 'she hid them', for example, the two speakers recorded never moved the tongue away from the alveolar ridge, a gesture necessary for the schwa element to surface. The occurrence of this element is thus linked to the amount of overlap between the two consonants: C_1 release must not be substantially overlapped by C_2 (i.e., C_1 release and C_2 closure should be spaced in time). Since articulatory coordination is not directly observable on acoustic data, and articulatory release may not always be visible acoustically, we will test this hypothesis with the help of an indirect argument: place order effect.

Several studies have shown that the overlap between consonants depends on their respective place of articulation. Back-to-front sequences (e.g., [kt]) have been shown to have less temporal overlap than front-to-back sequences (Chitoran et al. 2002; Kühnert et al. 2006). If this 'place order effect' holds true for Tashlhiyt, one would expect schwas to occur more frequently in back-to-front than in front-to-back clusters. Our results, illustrated in Figure 11, do not confirm this hypothesis. The distribution of [@] is not a function of the ordering of the place of articulation of the consonants in the cluster (χ^2[1, 574] = 1.4, p = .24). This result also holds when only stop + stop clusters are considered (χ^2[1, 150] = 1.7, p = .2) or when data without geminates are considered (χ^2[1, 556] = 1.2, p = .3). Schwa occurs in 53% of the back-to-front clusters (79% for stop + stop clusters) and in 48% of the front-to-back clusters (69% for stop + stop clusters).

An effect of place order is found on the relative duration of [@], which is longer in back-to-front than in front-to-back clusters (F[1, 289] = 10.5, p = .001). If [@] duration is indeed the acoustic reflex of the gap between C_1 and C_2 articulation, then the longer duration of this interval may be interpreted as a consequence of less overlap between C_1 and C_2 gestures in back-to-front sequences. Note, however, that this effect of place order on the duration of [@] disappears when only stop + stop clusters are considered (F[1, 109] = .1, p = .8).

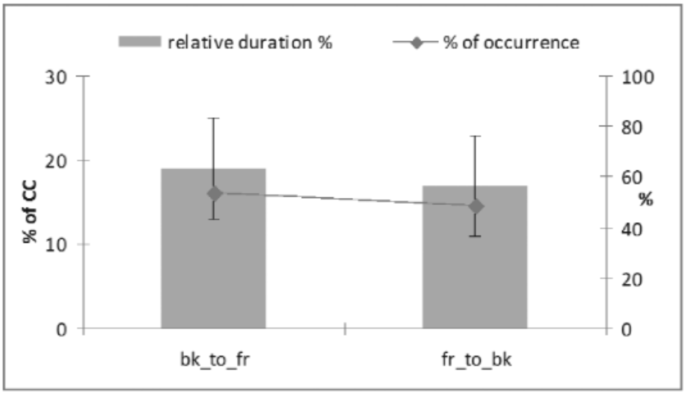

Figure 11. *Percentage of occurrence (curve, right axis) and duration (bars, left axis) of the schwas according to the order of place of articulation in the C_1C_2 sequence.*

4. Discussion

The aim of this study was to provide new insights into the nature of the schwa elements in some Tashlhiyt word-initial clusters. Specifically, we wanted to determine whether and how the phonetic characteristics of the adjacent consonants affect their distribution and their durational characteristics. In addition, we examined how the presence of this element affects the overall duration of the sequence where it occurs.

Concerning the temporal consequences of the presence of schwas within a cluster, our results show that they do not add extra duration to the sequences where they occur. Consequently, CC sequences with or without a schwa have virtually the same duration. Tashlhiyt schwa elements in this respect seem to differ from phonological schwas as reported in some languages, but pattern in the same way as non-segmental intrusive schwas. In Russian, Davidson and Roon (2008) found that word-initial sequences of two consonants separated by a phonological schwa (i.e., #CəC) exhibited significantly longer durations than #CC sequences. The authors also observed that some CC sequences displayed schwa-like elements (i.e., C@C). They compared the duration of these to the duration of phonological schwas, and found that the latter are significantly longer. In English, in addition to schwas resulting from vowel reduction, a schwa-like element may occur in some specific contexts (e.g., in sequences of high tense vowel + liquid as in *heel* or *hail*). Gick and Wilson (2006) analysed this not as a segment but as an incidental acoustic outcome of the tongue moving through 'schwa-space' during the transition from the glide to the liquid. As in Tashlhiyt, this schwa-like element does not add duration to the sequence where it occurs.[11] English speakers may also produce schwa-like elements within a phonotactically non-native CC sequence (Smorodinsky 2002; Davidson 2005). Davidson (2006) found that this intrusive material was consistently shorter than a lexical schwa, indicating that speakers were moving from one constriction to another without producing a vocal tract opening wide enough to correspond to a lexical schwa. According to her, this finding is consistent with the analysis of this schwa as a transitional element that is present on the acoustic record because the speakers have failed to produce the surrounding consonants with a sufficiently overlapping coordination. Salish languages have both intrusive and epenthetic schwas. Intrusive schwas are transitional elements which may be present acoustically but not phonologically. Epenthetic schwas, on the other hand, are present phonologically as well as acoustically and perceptually (Shahin and Blake 2004, and references therein). Shahin and Blake (2004) distinguish between epenthetic and excrescent (intrusive) schwa on phonetic grounds, and show that the latter are significantly shorter than the former.

Awaiting further investigation on how Tashlhiyt cluster duration is computed, we argue that the component of the grammar which determines the duration of a cluster ignores the presence of this schwa element in this computation. It does not ignore, however, the presence of a full vowel segment. As our data show, CiC sequences are consistently longer than C@C sequences. Other aspects of Tashlhiyt grammar indicate that [@] behaves differently from the segmental vowels /a, i, u/. Based on the behavior of dental stops vis-à-vis the process of assibilation, Ridouane (2008) provides evidence that two consonants not separated at the underlying level by one of the vowel /a, i, u/ are adjacent at the surface. This is true even of C@C sequences. Assibilation changes underlying /t/ and /d/ to [s] and [z], respectively, unless they are adjacent to a coronal consonant (/tudit/ 'butter' is realized [suzis], but in /tdum/ 'it lasts', which may be realized as [t@dum], or in /trza/ 'she is broken', realized as [t@rza], the /t/ remains unchanged). Although these forms may surface with a schwa element, this element does not disrupt adjacency between segments. This argument is analogous in principle to that of Dell and Elmedlaoui (2002), which makes use of regressive devoicing in Imdlawn Tashlhiyt. This variety, as well as the Agadir variety examined here (see below for more details), has a process of regressive devoicing applying in clusters of adjacent obstruents. In the perfective verb /s-uzf/ 'discover', for instance, the adjacency of /z/ and /f/ makes regressive devoicing possible, yielding [zu.sf]. The corresponding imperfective form of this verb is [zzuzuf], with a copy of the initial vowel inserted in the final cluster, thus making /z/ and /f/ non-adjacent and regressive devoicing impossible. Again, the assumption that the perfective form contains a schwa segmental vowel before the nucleus /f/ is problematic. This schwa element behaves as if it were not there, unlike the segmental vowel /u/ which disrupts the adjacency between the obstruents, making devoicing possible.[12]

Several authors have put forth formal analyses of how such schwa elements may surface. From the Articulatory Phonology perspective it is generally argued that they derive acoustically from a reduced gestural overlap between the flanking consonants. That is, if the consonants are not overlapped, a transitional vocoid may appear on the acoustic record corresponding to the period in which the vocal tract is relatively open and the vocal folds are vibrating (Price 1980; Browman and Goldstein 1989, 1992; Smorodinsky 2002; Gafos 2002; Hall 2003). Our results provide more insights on the phonetic contexts that favor the emergence of these elements.

The coordination between the laryngeal gestures in the sequence was found to be an important parameter that accounts for the acoustic occurrence of schwas. They only occur when at least one of the two flanking consonants is voiced. Moreover, schwas occur more frequently when it is the second consonant that is voiced.

In our view, the schwa in [k@d] and the voiceless release in [kt] both result from a specific timing coordination between supralaryngeal and laryngeal gestures. That is, in both [k@d] and [kt] clusters, there is a more or less long period of time between the articulatory release of the first oral gesture and the achievement of the target of the second oral gesture. Most of the acoustic information occurring within this interval depends on whether vocal folds are vibrating or not. The voiceless release of /k/ in [kt], on the one hand, displays aperiodic transient noise and a voiceless interval with frication noise (see Figure 5a). Voiceless /k/ in this context

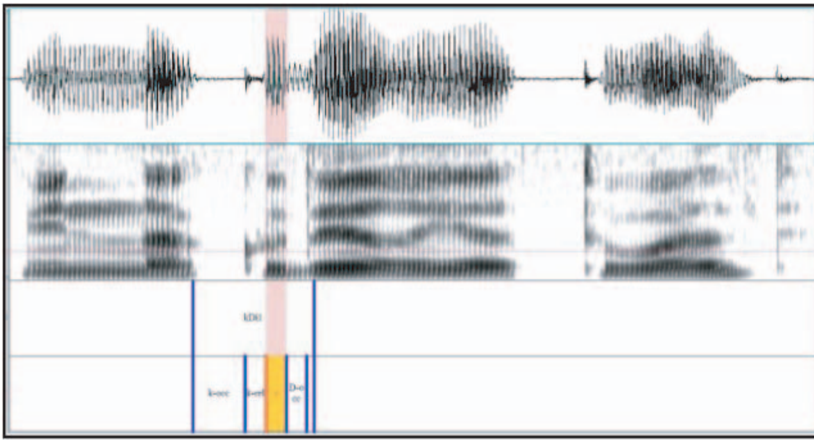

Figure 12. *Acoustic waveform and spectrogram of a [vl vd] cluster [kdˤ], illustrating the occurrence of a schwa after the release of the voiceless stop /k/.*

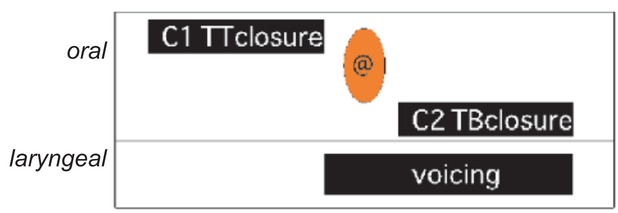

Figure 13. *Schematic illustration of the type of coordination between laryngeal and supralaryngeal gestures that accounts for the presence of a schwa in [vl vd] sequences.*

is produced with a large glottal opening (Ridouane et al. 2006, 2007). The noise following the release of this stop is not aspiration, in the sense of aperiodic energy created at the glottis. This is because the glottis area at stop release is greater than the oral constriction area so that the frication noise generated at the oral constriction becomes dominant over aspiration noise at the glottis. In [k@d], on the other hand, the first stop may not be produced with such a large glottal opening, since it is immediately followed by a voiced segment. Rather, the glottis displays a narrow glottal aperture, so that by the time this stop is released, the size of the glottal opening is so small that the voicing starts immediately after. The vocal fold vibration during the transition to the next segment yields an acoustic release displaying characteristics of a vocalic element. This is illustrated in Figure 12 and schematized in Figure 13.

The fact that schwas are less frequent in [voiced, voiceless] sequences is related to the tendency for voiced C_1 to devoice when followed by a voiceless obstruent.

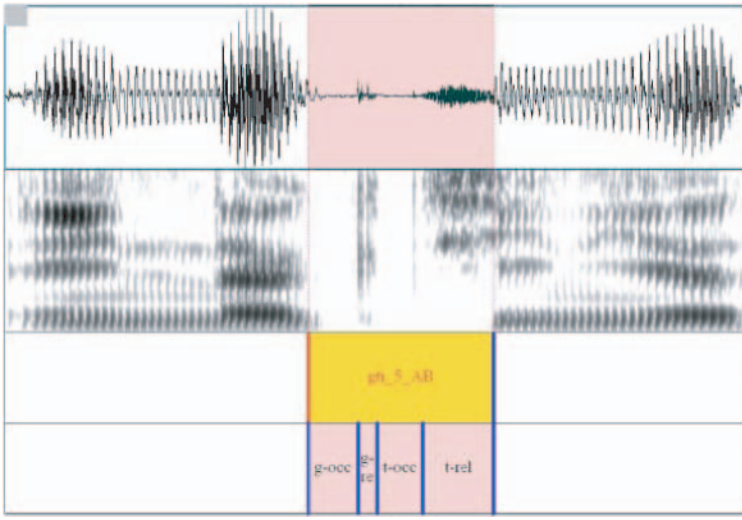

Figure 14. *Acoustic waveform and spectrogram of a [vd vl] cluster [gt], showing the devoicing of the first consonant closure.*

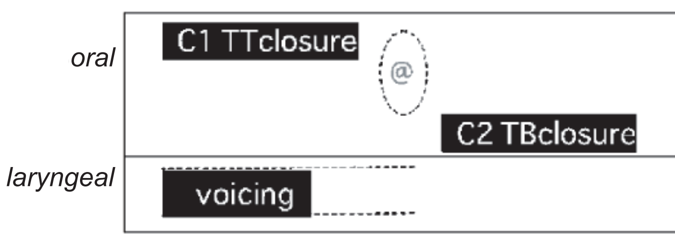

Figure 15. *Schematic illustration of the type of coordination between laryngeal and supralaryngeal gestures that accounts for the absence of a schwa in [vd vl] sequences.*

A closer examination of these clusters shows that out of 206 lexically [voiced, voiceless] clusters, 106 showed signs of devoicing during C1 closure (either partially or during the full closure). Of these 106 tokens 103 are produced with no [@]. Figure 14 illustrates such a case. In this context, maintaining vocal fold vibration throughout the consonant constriction may be particularly difficult, due to aerodynamic reasons. This provides an account for why such a voicing combination within a word initial sequence is rather uncommon cross-linguistically (Lombardi 1995). Kreitman (2008), based on a cross-linguistic survey of 43 languages, reported the existence of such clusters in only five languages with supporting phonetic evidence only in three: Modern Hebrew, Khasi and Tsou.[13] Given this, a schwa should not surface acoustically if, by the time the consonant is released, the vocal folds are no longer vibrating. This is schematized in Figure 15.

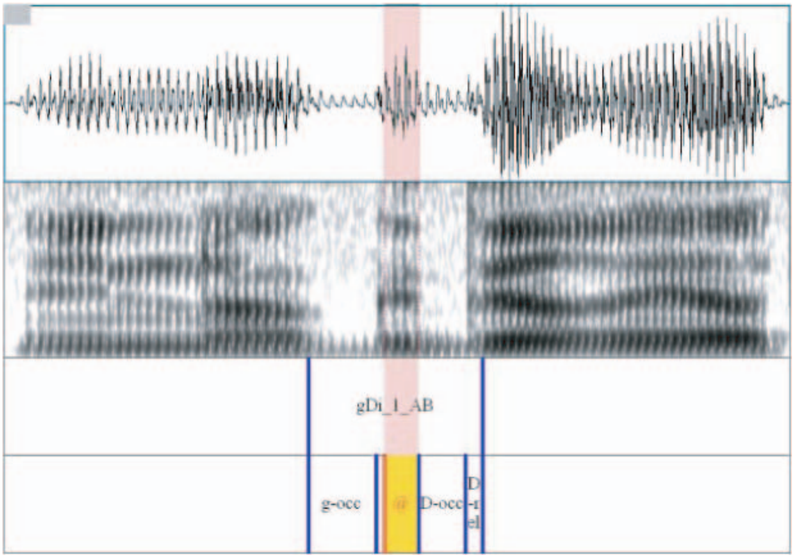

Figure 16. *Acoustic waveform and spectrogram of a [vd vd] cluster [gdˤ], showing a clearly visible schwa after the release of /g/.*

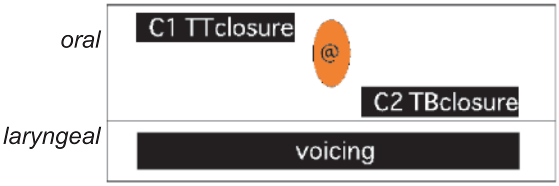

Figure 17. *Schematic illustration of the type of coordination between laryngeal and supralaryngeal gestures that accounts for the presence of a schwa in [vd vd] sequences.*

While this explanation holds for most of the devoiced [voiced, voiceless] sequences, three tokens out of the 106 were produced with a schwa. They correspond to three /gt/ clusters produced by RR. In these tokens, it seems that after a short cessation of voicing during the /g/ closure, vibration of the vocal folds restarts for a voiced release of the first consonant.[14]

In [voiced, voiced] sequences, in the absence of any trigger for devoicing, the consonants are both produced with vocal fold vibration throughout the cluster. With an open transition from C_1 release to C_2 closure, the conditions are met for schwa to surface. This is illustrated in Figure 16 and schematized in Figure 17. As shown by Zeroual and Hoole (2010) for Moroccan Arabic, this open transition may be motivated on aerodynamic grounds: a lag between the stops' constrictions allows for a decrease of intra-oral pressure at C_1 release which aids in maintaining voicing.

Concerning the effect of manner of articulation on the distribution of schwa elements, our data show that they occur more often in stop + stop sequences. In this context, the recoverability of the first consonant's place of articulation may be challenged if it is substantially overlapped. The view that the amount of overlap between gestures may be related to perceptual recoverability considerations has been proposed in several studies (Silverman and Jun 1994; Silverman 1995; Byrd 1996; Wright 1996; Chitoran et al. 2002). This perceptually driven constraint is of particular importance in a language like Tashlhiyt where lexical and morphological structure brings various types of consonants together in different prosodic positions. In word-initial stop-stop sequences, which are potentially also utterance initial, information on the place of articulation of the first consonant is mainly cued by the spectral information at its release (since there is no preceding vowel).[15] The presence of a voiced release, of a certain duration, and with a certain energy envelope would allow the cues to the place of articulation to be more distributed in time: in the burst, the noise transient, and in the transitions toward the schwa. A substantial overlap of C1 by C2, on the other hand, will not only reduce information about the identity of C1 (and also C2) but will potentially result in a perceptual confusion with word-initial geminates, which are frequent in the language. In a form like [bdiʁ] 'I started', for example, the initial consonant cannot be substantially overlapped without risking the confusion with [ddiʁ] 'I went'.

In clusters containing a fricative, the presence of cues to the place of articulation at the CC transition is not as important as for stops. One reason is that fricatives have more internal cues to place of articulation during the constriction phase, and frication noise carries transitional information at the CC boundary (Kingston 1990; Wright 1996). The presence of a transitional [@] element is thus not as strongly required. In our data, it is indeed in the clusters containing a fricative that schwas are less frequent, occurring in about half of the tokens.

The absence of place order effect on the frequency of [@] occurrence can also be explained by the constraint on the coordination of supralaryngeal gestures at play in Tashlhiyt. If overlap is limited so that C_1 release is not masked by C_2 closure, a place order effect is not expected in this language, since all consonants have to be released regardless of how they are ordered in terms of their place of articulation.

To further test the relationship between consonantal overlap and [@] occurrence, we report here articulatory data for one of the speakers (RR) collected with electropalatography. These data were originally collected for a study examining how vowel-less syllables and their constituents are phonetically implemented (Fougeron and Ridouane 2008b). They are worth a reanalysis for their relevance to the question at issue here, namely whether the occurrence of [@] is related to the degree of overlap in the sequences. The corpus contained 12 repetitions of 18 items with three-consonant sequences (e.g., [tkti] 'she remembered', [ngn] 'we

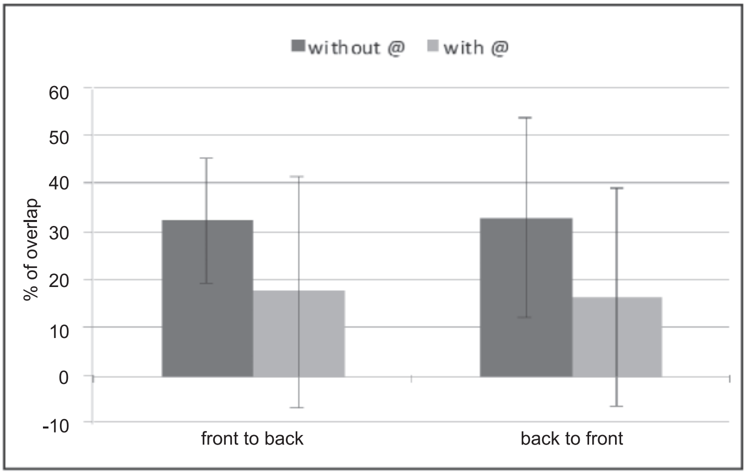

Figure 18. *Percentage of overlap according to place order, and presence of @ in the sequence.*

slept'). C_1 was either /n/ or /t/, C_2 was /k/ or /g/, and C_3 included a larger variety of consonants (all alveolars): /t, s, n, z, dˤ/.[16] In order to test for an effect of the degree of overlap on [@] occurrence and for an effect of place of articulation on overlap, we examined whether schwas were present in the acoustic records of the productions and compared C_1C_2 for front-to-back sequences (e.g., /tg/) and C_2C_3 for back-to-front sequences (e.g., /gdˤ/).[17] The overlap between the consonants was estimated from the evolution of linguopalatal contact in the alveolar and velar regions throughout the sequence.[18]

The EPG results are in accordance with our acoustic study. As expected, and as shown in Figure 18, the amount of overlap between the consonants is significantly larger in sequences without a schwa (33%) than in sequences with a schwa (17%) ($F[1, 384] = 41$, $p < .0001$) and the degree of overlap is similar in front-to-back clusters (21%) and in back-to-front sequences (29%) ($F[1, 384] = .01$, $p = .9$). While further investigation is needed, the constrained coordination between the supralaryngeal gestures in Tashlhiyt could explain the occurrence of schwa in some sequences as well as the absence of a place order effect.

We have also presented data on the effect of manner, place and voicing on the durational characteristics of the schwas. Results show that their duration is longer in [voiced, voiced] sequences compared to sequences where only one consonant is voiced, in fricative-fricative clusters compared to other combinations of manner of articulation, and in back-to-front compared to front-to-back clusters. It is not clear, however, whether these differences in duration are related to specific gestural coordination patterns or whether they are the consequence of our segmentation criteria. On the one hand, longer schwas in back-to-front sequences could be the consequence of less overlap. However, this interpretation does not accommodate the absence of a place order effect on overlap found in our EPG data and in the stop-stop cluster analysis. On the other hand, in [voiced, voiced] and fricative-fricative sequences, the longer duration could be explained by the fact that boundary cues for the segmentation of the schwa element are the least clear-cut in these cases, compared to other sequences.

5. Conclusion

In this paper we have examined the phonetic factors that govern the distribution and the durational characteristics of the schwa element in Tashlhiyt word-initial CC clusters. The results obtained show that the duration of CC with and without schwa is virtually the same. The study further shows that specific acoustic and articulatory conditions favor or inhibit the emergence of this element. For a schwa element to surface acoustically at least two conditions should be met: (1) the vocal tract has to be sufficiently open during the transition from one consonant configuration to the next, and (2) at least one of the consonants in the sequence should be voiced. Future work is called for to examine additional word positions and to test the perceptual motivations hypothesized to constrain gestural coordination in Tashlhiyt.

Appendix

Transcription, morphological structure and translation of the Tashlhiyt items presented in Table 2. cau: causative, s: singular, m: masculine, do: direct object, p: plural

bdi-ʁ	start-1s	I started
gdˤi-ʁ	flow-1s	I flew
t-gi-m	2-to be-2mp	You were
kdˤi-ʁ	smell-1s	I smelled
bqi-ʁ	stay-1s	I stayed
g=t=inn	put=do3ms=dir	put it there
t-qijs	3f-try on	She tried on
kti-ʁ	remember-1s	I remembered
bzˤiz	surname	Surname
gzi-ʁ	to be disgusted-1s	I was disgusted
tˤʁi-ʁ	corrupt-1s	I corrupted

bsi-ʁ	melt-1s	I melted
ddf iʃ	wildness	Wildness
t-ʃib	3f-be old	She is old
ksi-ʁ	feed on-1s	I fed on
zgi-ʁ	stop-1s	I stopped
zbi-ʁ	steal-1s	I stole
s-gin	cau-sleep	make one sleep
ʜbi-ʁ	hide-1s	I hid
zki-ʁ	give alms-1s	I gave alms
ʕtiq	rescue	Rescue
fki-ʁ	give-1s	I gave
χti-ʁ	quarrel-1s	I quarrelled
fsi-ʁ	untied-1s	I untied
χsi-ʁ	choke-1s	I choked
zzʁur	spread out	Spread out
ʁzi-ʁ	dig-1s	I dug
sʁi-ʁ	buy-1s	I bought
χzi=t	insult-do3ms	Insult him
ʒʒʜid	fierceness	Fierceness
ʕfi-ʁ	forgive-1s	I forgave

Acknowledgments

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Correspondence email address: rachid.ridouane@univ-paris3.fr

Notes

1. Throughout this paper, slashes are used for transcription of ‘underlying forms’ (morphemic transcriptions), brackets are used for broad phonetic transcription, hyphens mark morphological boundaries inside words, and equal signs mark boundaries between clitics and their hosts. Nuclei consonants are underlined, and periods are used to mark syllable boundaries.
2. A third alternative, which we do not consider here, is to argue that such forms are not composed of syllables at all. Evidence has already been provided showing that such consonantal sequences are made up of syllables. Some of these are briefly presented in this article.
3. Note, however, that some Tashlhiyt items, borrowed from Moroccan Arabic, may contain a sequence of two back consonants. In these items, C_1 is most often an aryepiglottal fricative (e.g., /ʜgr/ ‘to despise’).
4. One exception concerns schwas occurring next to /r/. These schwas reflect the instances where the taps of the alveolar trill are almost always accompanied by short, central vocoids.
5. As Coleman noted, this form, borrowed from Arabic /alqissa/, is often produced with a full vowel /i/ and can thus be represented as /lqistt/.
6. In Dell and Elmedlaoui’s model all these CC sequences span a syllable boundary, where the first consonant is a coda and the second consonant is the onset of the following syllable (e.g., [in.nab.di]). Under this syllabification, any vocalic element occurring between the two consonants is considered as a non-nuclear element. In Coleman’s model, however, the first consonant in ≠CC could also be an onset, with any following schwa as the phonetic realization of an empty nucleus.
7. RR is the first author.
8. This second recording, suggested during the review process, was done subsequently to confirm that schwas do not occur within voiceless clusters and to compare full vowels and schwas in terms of added duration in a C_C sequence. The recording could not be done with the same 5 subjects as two of our first set of speakers had left France since then.
9. One repetition of [zgiʁ] was excluded from the analysis as it was misproduced by AB.
10. See Ridouane (2008) on the issue of devoiced schwa vowels and their absence within voiceless obstruent clusters. Data were based on acoustic as well as photoelectroglottographic examination of various voiceless clusters. In this paper, potential devoiced schwas are not considered.
11. Based on English data from Lavoie and Cohn (1999). They reported that the occurrence of this vocalic element within the sequence [aj@l] (201 ms) does not translate into extra duration of this sequence, compared to [ald] (213 ms) and [ajd] (185 ms).
12. A possible alternative to the analysis posited here would be to argue that schwa is inserted after the process of assibilation or regressive devoicing. But see Ridouane (2008), who discusses and rejects this alternative analysis.
13. Moroccan Arabic is another language having word-initial [voiced, voiceless] clusters, e.g., /bka/ ‘he cried’
14. A perceptually driven constraint may be at work here. Consider the following minimal pair for illustration: [ktid] ‘remember’ vs. [gtid] ‘put it here’. The release of /g/ into a more open vocal-tract configuration, having the acoustic envelope of a vocalic element, will preserve the contrast even though devoicing occurs during its closure.
15. In our data, these CC sequences are utterance-internal, preceded by the vowel /a/. Formant transitions from a preceding vowel may thus be available. VC transitions are, however, less informative about stop consonant identity than CV transitions (Pickett et al. 1995).
16. The number of items per cluster type was [tk]*3, [nk]*6, [tg]*3, [ng]*6 for the front-to-back (C_1C_2) sequences, and [kt]*3, [ks]*3, [kn]*3, [gz]*3, [gn]*3, [gdˤ]*3 for the back-to-front (C_2C_3) sequences.
17. C_1C_2 sequences comprise onset-nucleus, nucleus-coda and nucleus-onset sequences, and C_2C_3 sequences comprise nucleus-onset, coda-onset, and onset-nucleus sequences.

18. See Fougeron and Ridouane (2008b) for an explanation on the procedure used to define these two regions. In front-to-back sequences, we measured the percent of the duration of the alveolar contact for C1 overlapped by the velar contact of C2 (i.e., how early the velar contact of C2 occurs during the linguopalatal articulation of C1, expressed as a percentage of C1 alveolar contact duration). In back-to-front sequences, we measured the percent of the duration of the velar contact of C2 overlapped by the alveolar contact of C3 (i.e., how early the alveolar contact of C3 occurs during the linguopalatal articulation of C2, expressed as a percentage of C2 velar contact duration).

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