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*Georgian harmonic clusters: phonetic cues to phonological representation**

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1 Introduction

Georgian, a South Caucasian language belonging to the Kartvelian family, is characterised by the ability of its consonants to combine in extensive clusters. Among the possible combinations are a series of two-member clusters which are argued to behave phonologically as single segments (Tschenkeli 1958, Vogt 1958, 1971, Aronson 1982, 1991, Deprez 1988 and others). They are known as 'harmonic' clusters, because the laryngeal quality is constant across the cluster. Its two members are both voiced ([dg bg dɣ bɣ]), both aspirated ([t^hk^h ts^hk^h $t^h\chi$ $ts^h\chi$]) or both ejective ([t'k' ts'k' p'k' t'q' ts'q']). They can occur either word-initially or in word-medial position. Harmonic clusters do not contrast with identical sequences of segments, except for sequences formed at the junction of two words. There is no evidence that across word boundaries harmonic clusters are derived by some sort of restructuring.

The purpose of the present study is to review the phonological arguments brought in the literature in favour of treating harmonic clusters as single segments, and to look for acoustic evidence that would motivate the distinction made between harmonic clusters behaving as single segments, on the one hand, and simple sequences of consonants, on the other hand. The study uses phonetic data to address the issue of phonological representation. If the difference between a harmonic cluster and a simple sequence of segments is present in the phonology, then it should ideally also be visible in the acoustic signal, for example in the presence or absence of a release burst, or in timing differences, as suggested by previous studies of complex *vs.* simple segments in various languages (Maddieson & Ladefoged 1989, Maddieson 1989, 1990). The

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results show that the treatment of Georgian harmonic clusters as complex segments is not supported by the acoustic data.

The paper is organised as follows: § 2 presents the phonological behaviour of consonant clusters in Georgian, § 3 reviews phonetic evidence for complex segments, and spells out the predictions made by the present study. The acoustic study is described in § 4, followed by the presentation and discussion of results in § 5. The conclusions and areas for further study are presented in § 6.

2 The phonological behaviour of clusters

Georgian allows the formation of long clusters. The consonantal inventory of Georgian is given in (1).

(1) *The consonantal inventory of Georgian*

		LABIAL	CORONAL		DORSAL		
			dental	palatal	velar	uvular	glottal
stop	voiced	b	d		g		
	aspirated	p^h	t^h		k^h		
	ejective	p'	t'		k'	q'/q'χ	
affricate	voiced		dz	ʤ			
	aspirated		ts^h	ʧ^h			
	ejective		ts'	ʧ'			
fricative	voiced		z	ʒ		ɣ[1]	
	voiceless		s	ʃ		χ	h
nasal		m	n				
liquid			r,l				
glide		w/v					

Orthographic ⟨v⟩ stands for the bilabial glide [w], especially after consonants, and for the labiodental fricative [v] elsewhere. In the stop and affricate series Georgian has a three-way opposition: voiced, voiceless aspirated and voiceless ejective. Fricatives have only a two-way opposition: voiced–voiceless.

Long consonant clusters are attested in all positions in the word: initially, medially and finally. I do not treat final clusters in this study, since the type of clusters known as 'harmonic' are not attested word-finally. Moreover, word-final clusters always include inflectional endings, as shown below:

[1] The standard IPA symbol for a voiced uvular fricative is [ʁ], but [ɣ] is used by all Georgian grammars, and will be used in this study.

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(2) ort^{h}k^{h}l-i 'steam (NOM)' ort^{h}k^{h}l-s 'steam (DAT)'
marts'q'v-i 'strawberry (NOM)' marts'q'v-s 'strawberry (DAT)'
v-χet^{h}k^{h}-av 'I crack' v-χet^{h}k^{h}-av-t^{h} 'we crack'

It is not clear how the clusters are syllabified. With the exception of a brief section in Tschenkeli (1958), none of the Georgian grammars I consulted contains a systematic account of syllabification, and the six native speakers I had access to had mixed intuitions about the location of the syllable boundary in the case of long word-internal clusters.

Some of the word-initial clusters are formed at a prefix–root boundary, by the addition of inflectional prefixes, sometimes as a result of vowel syncope. Some examples containing pronominal prefixes are given in Vogt (1958).

(3) t'eχv-a 'to break' v-t'eχ 'I break it'
gv-t'eχ 'you break us'

Vogt (1958) classifies obstruent clusters depending on two main factors: (i) the successive places of articulation of the members of the cluster and (ii) their laryngeal specification.

In terms of the first factor, clusters can be regressive, beginning with a phoneme with a front constriction, and followed by a phoneme whose constriction is further back (e.g. labial–coronal, coronal–dorsal, labial–dorsal). Other clusters are non-regressive, back to front (e.g. dorsal–coronal, coronal–labial, dorsal–labial).

In terms of the second factor, clusters are 'homogeneous' and 'non-homogeneous'. In homogeneous clusters, the laryngeal feature is constant across the cluster. All its members are either voiced, aspirated or ejective.

The acoustic study investigates the clusters which are homogeneous and regressive, and which are referred to as 'harmonic'. A complete list is given in (4).

(4) a.	corono-velar	voiced	dg	dzg	ʤg
		aspirated	t^{h}k^{h}	ts^{h}k^{h}	ʧ^{h}k^{h}
		ejective	t'k'	ts'k'	ʧ'k'
b.	corono-uvular	voiced	dɣ	dzɣ	ʤɣ
		aspirated	t^{h}χ	ts^{h}χ	ʧ^{h}χ
		ejective	t'q'	ts'q'	ʧ'q'
c.	labio-velar	voiced	bg		
		aspirated	p^{h}k^{h}		
		ejective	p'k'		
d.	labio-uvular	voiced	bɣ		
		aspirated	p^{h}χ		
		ejective	p'q'		

They occur in word-initial and word-medial position, as illustrated in (5):

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(5) *Words containing harmonic clusters*

a. *voiced*

bgera	'sound'	dɣe	'day'
ʤibgiri	'hooligan, thief'	dɣveba	'to spread butter'
bɣavili	'to shout'	asdɣiani	'100 days long'
gabɣverili	'blown up'	midzɣvna	'dedication'
dgoma	'standing'	ʤgupʰi	'group'
sadguri	'station'		

b. *aspirated*

pʰkʰvili	'flour'	sitʰχe	'fluidity'
pʰχizeli	'sober, awake'	tʰχovna	'request'
mtʰkʰnareba	'to yawn'	tsʰkʰera	'looking'
tʰkʰma	'to say'	ʃevatsʰkʰerdi	'to stare'
tʰkʰven	'you (PL)'	tsʰχovreba	'life'
datʰkʰma	'to agree'		

c. *ejective*

p'k'ureba	'to sprinkle'	sit'q'va	'word'
p'q'robili	'conquered'	ts'q'ali	'water'
sap'q'robile	'jail'	gadats'q'vet'a	'solution'
t'k'ivili	'pain, ache'	ʧ'k'ua	'intelligence'
t'q'e	'forest'	ʧ'k'viani	'intelligent'

In addition to the homogeneity of laryngeal features, a number of other criteria are listed as characterising harmonic clusters. They are reviewed below.

(6) *Properties characterising harmonic clusters*

a. homogeneity of laryngeal features (cf. all of the authors cited below in (b)–(d))
b. regressive in terms of articulation
(Rudenko 1940, Axvlediani 1949, Tschenkeli 1958, Žgenti 1965, Chikobava 1967, 1971, Catford 1977, Gamkrelidze 1966, Fähnrich 1986 for Modern Georgian, 1991 for Old Georgian)
c. tautosyllabicity
(Tschenkeli 1958, Žgenti 1965, Vogt 1971)
d. no optional [r]-insertion
(Vogt 1958, 1971, Chikobava 1971, Deprez 1988)
e. simultaneity of closure and release
(Žgenti 1965, Aronson 1982, 1991)

The first two properties, (a) and (b), have already been discussed. With respect to the third property, harmonic clusters are reported to be tautosyllabic by some authors, while non-harmonic groups are reported to be heterosyllabic in word-medial position. Unfortunately, no independent

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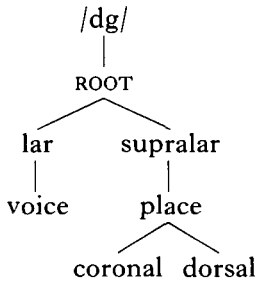
evidence is given to support the syllabification patterns above, and the six native speakers I worked with did not agree on the location of the syllable boundary. Given the absence of reliable information, I will not discuss property (6c) in this paper.

Regarding the fourth property, (6d), notice that the two members of harmonic clusters are never separated by an optional [r], as non-harmonic clusters sometimes are. Thus, [gdzeli] and [grdzeli], containing a non-harmonic cluster (non-regressive), both mean 'long', and are in free variation. Although sequences such as [bg] and [brg] can both be found in Georgian, they occur only in different lexical items: [bgera] 'sound', [brge] 'high'.

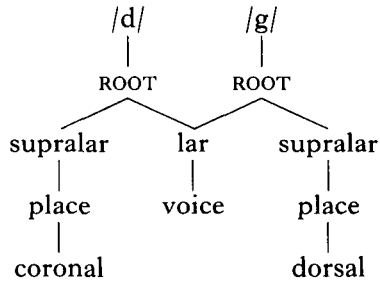
With respect to the fifth property, (6e), a number of authors (Žgenti 1965, Aronson 1982, 1991, Deprez 1988) describe the two members of a harmonic cluster as having simultaneous closures and only one release. This description is purely impressionistic.[2]

On the basis of such descriptions, Deprez (1988) concludes that harmonic clusters should be treated as single, doubly articulated stops. She proposes to represent them as complex segments in the model developed by Sagey (1986). In this model, harmonic clusters can be represented as consisting of one root node (7a), as opposed to two separate root nodes (7b).

(7) a.



b.



The representation in (7a) captures the basic properties of the clusters identified as harmonic: they pattern as a single consonant, and they are phonetically simultaneous (their closures cannot be separated, they have only one release). The laryngeal node is filled by only one specification (either [voice], [spread glottis] or [constricted glottis]), which implies homogeneity of laryngeal features.

Treatments of consonant clusters as complex segments have been proposed for Kabardian by Kuipers (1960), Anderson (1978) and Padgett (1991). Anderson, for example, analyses ejective clusters such as /t'p'/ as complex segments. He relates their unitary phonological behaviour to

[2] As pointed out by one anonymous reviewer, these descriptions of the articulation of harmonic clusters are somewhat surprising, given the fact that they conflict with the traditional notation used for them. The transcription in fact indicates their sequential structure, with aspiration or ejection of each release (e.g. [t^hk^h t'k']).

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their articulatory nature, consisting of a sequence of two oral articulations associated with a single laryngeal gesture. However, most of the phonological arguments brought in support of Kabardian harmonic clusters as complex segments do not hold for Georgian.

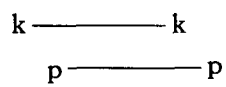
Although all the clusters listed in (4a–d) are referred to as harmonic, there exists an asymmetry between coronal–dorsal and labial–dorsal clusters (Vogt 1958, 1971, Chikobava 1971, Deprez 1988). Coronal–dorsals may be members of three-stop clusters, but labial–dorsals may not. Coronal–dorsals allow the combinations stop[coronal–dorsal], as in [bdɣviri] 'cloud of dust', or [coronal–dorsal]stop, as in [t'k'bili] 'sweet'. Similar clusters containing labial–dorsal harmonic groups, such as *[$p^h k^h d$], for example, are not attested. Based on this asymmetry, Deprez (1988) proposes that all coronal–dorsal harmonic clusters should be analysed as complex segments, while labial–dorsal harmonic clusters can be either true clusters or complex segments, based on lexical distinction.

Having presented the phonological behaviour of the Georgian harmonic clusters, in the following section I review cross-linguistic phonetic evidence for the distinction between consonant clusters functioning as complex segments and those functioning as sequences of simple segments.

3 Phonetic evidence for complex segments

From an articulatory point of view, complex segments are characterised as segments with double, simultaneous articulations, as opposed to sequential articulations in a sequence of simple segments. For a complex segment whose two members are stops, simultaneous articulation implies that the closure of the second stop is formed before the closure of the first stop is released (Maddieson & Ladefoged 1989). In the acoustic signal this difference translates into the absence of the first release burst in simultaneous articulations *vs.* the presence of the first release burst in sequential articulations. Ladefoged & Maddieson (1996) report a single stop release for complex segments such as Eggon labio-velars [k͡p] and [g͡b], while separate releases are clearly seen in stops in a sequence. The authors think that the velar release occurs shortly before the labial one, but it is not heard, nor visible in acoustic records. The relative timing of the two closures is shown schematically below (Maddieson & Ladefoged 1989: 122).

(8) *Relative timing of the two closures in* [k͡p] (*schematic illustration*)



The following prediction can be made for Georgian. If harmonic clusters are complex segments, then the first member of the cluster should

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systematically lack a release burst, as opposed to a sequence of stops, where each stop has its own release (Henderson & Repp 1982).

Another important cue in distinguishing a doubly articulated segment from a sequence is segment duration. Doubly articulated stops and nasals, for example, have very similar durations to stops and nasals with single articulations. Maddieson & Ladefoged (1989) found that Yoruba /g͡b/ and /b/ have similar durations. The labio-velar /g͡b/ in /àg͡bà/ 'jaw' has a mean duration of 132 ms, and a simple /b/ 128 ms. This difference is not statistically significant, while sequences of two segments were found to be typically one and a half to two times the duration of single segments of similar type. In the same study, the sequence in Eggon /kpu/ 'kneel' is reported to have roughly twice the duration of the labio-velar in /k͡pu/ 'die'.

A similar result was found for prenasalised stops *vs.* nasal–stop sequences. The duration of prenasalised stops is comparable to that of single segments (Burton *et al.* 1992 for Moru; Maddieson 1989 for Fijian).

Similar timing differences may be expected for Georgian. If a segment with two simultaneous articulations is roughly as long as a single articulation segment, then harmonic clusters as complex segments are expected to be shorter than a sequence of two single segments. This prediction is more difficult to test for Georgian, since no minimal pairs exist which contrast harmonic clusters and consonant sequences containing the same segments.

The two predicted differences are schematised below:

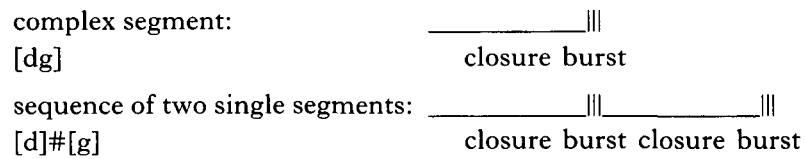


Figure 1
Predicted difference between harmonic cluster ([dg]) and sequence ([d]#[g]).

The remainder of this paper examines acoustic data, in search of evidence for the proposed representation of the harmonic clusters in (7). A decision must be made, therefore, between their representation as a sequence of two place features within one segment, as in (7a), and as a sequence of two segments with different place features, as in (7b).

An earlier phonetic study of Georgian (Robins & Waterson 1952) investigates the segmental and prosodic features of the Georgian word, based on kymograph tracings of the speech of one speaker. The authors give a detailed phonetic description of the vowels and consonants of Georgian, as well as of word stress. In their description of voiced consonant clusters, they mention the presence of a short, 'neutral' vowel sound, similar to [ə], between two voiced consonants, as in the words [dgoma] 'standing' and [gdeba] 'to throw'.

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Another interesting observation refers to the aspirated and ejective consonant clusters, in words such as [ʧ'k'ua] 'intelligence' and [t^hk^hwen] 'you'. Each consonant of the cluster is reported to be released, and the glottalisation or aspiration is maintained in each consonant. Both findings contradict the claims made about simultaneity of closure and single release of Georgian harmonic clusters, unless, of course, they simply reflect an idiosyncrasy of the one speaker in the study.

The phonetic experiment presented in the next section provides an acoustic description of similar kind of data, based on the speech of six native speakers. This is, to the best of my knowledge, the first attempt to use acoustic data to test the claims made about the structure of Georgian harmonic clusters.

4 Acoustic study

As mentioned earlier, Georgian harmonic clusters do not contrast with consonant sequences consisting of the same segments.[3] No minimal pairs are therefore available for comparison. The list prepared for the study consists of near-minimal pairs. It includes lexical items in which the coronal–dorsal and labial–dorsal harmonic clusters are morpheme-internal, and occur in word-initial and word-medial position (e.g. [bgera] 'sound', [ʤibgiri] 'hooligan'). The word-medial harmonic clusters contrast with sequences of consonants formed at the junction of words (e.g. [egeb gip'ovis] 'perhaps he will find you').

Ejective clusters were also recorded, but since no ejectives occur word-finally, no near-minimal pairs can be formed to contrast with the word-internal ejective harmonic clusters. Representative waveforms and spectrograms of the ejective clusters are shown below in § 5.1, but their measurements are not included in the statistics.

The word list is given in (9) below. Stress in Georgian is reported to be weak, with no sharp differences in intensity (Vogt 1971). I do, however, indicate the vowel which I hear as the most prominent, marked with an acute accent. The vowel with secondary prominence is marked with a grave accent:

(9) *Harmonic clusters*

a. *word-initial*

dgóma	'standing'	t^hχá	'goat'
dɣé	'day'	ts^hχéli	'hot'
bgéra	'sound'	t'k'ívili	'pain'
bɣávili	'crying'	ts'k'néli	'rod'
t^hk^hmá	'saying'	ʧ'k'úa	'intelligence'
ts^hk^héra	'to stare'		

[3] Henceforth the term CLUSTER will be used to refer to potentially non-sequential structure (complex segment), and the term SEQUENCE to refer to sequential structure.

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word-medial

áɣdgoma	'resurrection, Easter'	gátʰχòveba	'to get married'
ásdɣìani	'100 days long'	sítsʰχe	'heat'
ʤíbgiri	'hooligan'	áp'k'i	'membrane'
gábɣvèrili	'blown up'	sát'k'ìvari	'worry'
dátʰkʰma	'to agree'	gáts'k'èp'lva	'to beat with a rod'
ʃévàtsʰkʰerdi	'to stare for long'		

b. *sequences*

sád gíp'ovo	sad gi-p'ov-o where human-find-you	'where do I find you?'
rád ɣirs	rad ɣirs question-marker price	'is it worth it?'
égeb gíp'ovis	egeb gi-p'ov-is perhaps human-find-FUT/you	'perhaps he will find you'
égeb ɣória		'perhaps pig'
albátʰ kʰari		'probably wind'
métsʰ kʰáli var	me-tsʰ kʰali var I-too woman be	'I am a woman, too'
albátʰ χári		'probably ox'
métsʰ χári var	me-tsʰ χari var I-too ox be	'I am an ox, too'

Each token was repeated three times. The tokens were written in Georgian orthography, and read in isolation.[4] Fillers were inserted at the beginning and end of each block of ten words, and at the beginning and end of each page.

All six speakers recorded for this study, four male and two female, are bilingual native speakers of Georgian and Russian. They were instructed to read the phrases/sentences containing consonant sequences as if they were one word and without changes in intonation, in order to control for possible effects of word boundary. The recordings were made on a portable Marantz tape recorder, with an AKG microphone, model D310.

The tokens were digitised on a SPARC station LX, at a sampling rate of 11 kHz, and processed by the Entropic ESPS/Waves+ software package. The frequency of the occurrence of a release burst was reported, based on waveforms and wideband spectrograms. Although this information is sufficient to answer the question raised in the study, I also investigated possible duration differences between harmonic clusters and consonant sequences. These results, however, are not entirely reliable,

[4] At the time of the recording my main goal was to investigate the presence/absence of a release burst, rather than duration differences. The tokens were therefore not embedded in a frame sentence. Unfortunately, the speakers were only available for a short period of time, and I was unable to make new recordings for a controlled comparison of duration differences.

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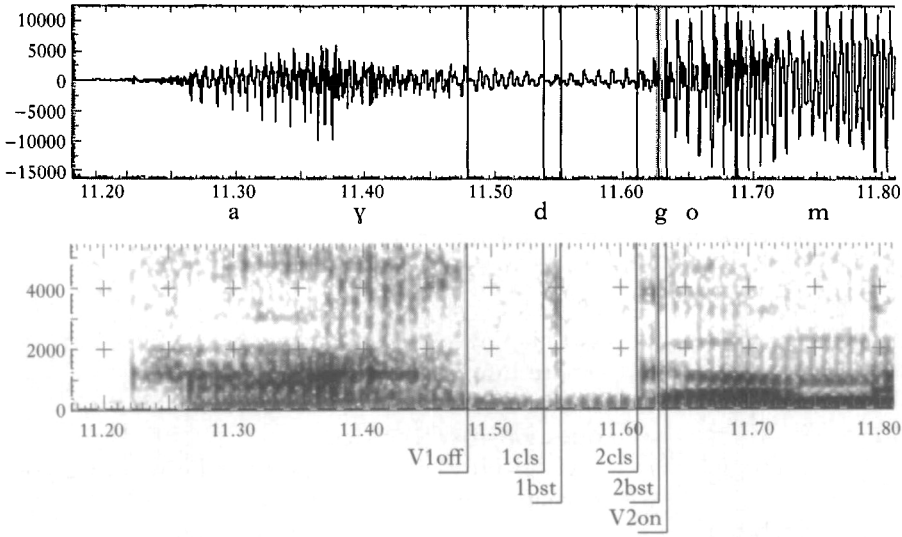


Figure 2
Labelled waveform and spectrogram of part of [aɣdgoma] 'resurrection' (speaker DB).

The following conventions are used throughout the paper:

V1off indicates the offset of the vowel preceding the consonant cluster, marked at F2 offset.

1cls marks the end of the closure of the first consonant (not marked for word-initial clusters). If the consonant is preceded by a vowel, the closure duration is measured from F2 offset to onset of C1 release; if C1 is preceded by a fricative, the closure is measured from the offset of frication to the onset of C1 release.

1bst marks the offset of C1 release, the first burst of energy after C1 closure. For word-initial clusters, the same label marks the onset of C1 release as well.

1asp marks the end of the portion of aspiration following the C1 release in an aspirated cluster.

2cls marks the end of the closure of the second member of the cluster, measured from the offset of C1 release to the onset of C2 release (often coincides with V2on).

2bst marks the offset of C2 release, the first burst of energy after C2 closure.

2asp marks the end of the portion of aspiration following the C2 release in an aspirated cluster.

V2on indicates the onset of the vowel following the consonant cluster, marked at F1 onset.

since the compared tokens do not have the same number of syllables, and were not recorded in a carrier phrase. I measured the duration of the entire cluster, as well as the duration of each individual acoustic parameter of each member of the cluster (closure, release burst, frication).

A labelled waveform and spectrogram for the word [aɣdgoma] 'resurrection' are shown in Fig. 2. In affricates the release burst could not

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be separated from the following frication. Therefore, the burst label is placed after the entire portion of frication.

The results of the study are discussed in the next section.

5 Results and discussion

I first present and discuss the presence/absence of the first release burst in § 5.1, and the additional results of durational measurements in § 5.2.

5.1 Characteristics of the release burst

A significant finding is the clear presence of two release bursts, visible on both waveforms and spectrograms. This result confirms the observation made by Robins & Waterson (1952) in their study based on the speech of one speaker (except for the presence of the 'neutral' vowel). Most of the harmonic clusters, voiced, aspirated and ejective, have two release bursts, one for each member of the cluster, as opposed to only one final release, as claimed in some of the earlier descriptions. Two bursts are visible both in word-initial and in word-medial harmonic clusters. The frequency of occurrence of release bursts for voiced and aspirated clusters is shown in Table I:[5]

	word-initial clusters	*word-medial clusters*	*sequences*
burst1 present	103 (95%)	99 (91%)	102 (94%)
total 108			$\chi^2 = 1{\cdot}38$
burst2 present	72 (100%)	67 (93%)	72 (100%)
total 72			$\chi^2 = 30{\cdot}92$

[Table I. Frequency of occurrence of release bursts (voiced and aspirated)]

The differences in the frequency of occurrence of the first release burst are not significant by a chi-square test ($\chi^2 = 1{\cdot}38$, df = 2) at p = 0·05. This shows that clusters and sequences pattern together in this respect. The impressionistic claims made in the literature are therefore not supported by the acoustic data: word-initial and word-medial harmonic clusters have a separate closure and release for each member of the cluster.

The release burst of the second consonant is always present in word-initial consonant clusters and in sequences (100 %). Fewer word-medial clusters (93 %) have a second release burst. This difference is significant by a chi square test ($\chi^2 = 30{\cdot}92$, df = 2) at p = 0·05. However, all the five tokens in which the second burst is missing are the same, namely the word

[5] The frequency of occurrence of the first release burst was calculated over the clusters and sequences [dg bg dɣ bɣ t^hk^h $t^h\chi$]. The frequency of occurrence of the second release burst was calculated over the clusters and sequences [dg bg t^hk^h ts^hk^h].

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[dat^{h}k^{h}ma], containing a word-medial aspirated cluster. In all of these tokens, the [t^{h}] burst is followed only by a portion of aspiration, and in one case, glottalisation. The cues of the velar stop are, however, preserved in the formant transitions into the following bilabial nasal. They are visible throughout the aspiration portion.

In Table II I report separately the percentage of occurrence of release bursts for ejective word-initial and word-medial clusters.

	word-initial clusters	*word-medial clusters*
burst1 present	18 (100%) *total* 18	35 (97%) *total* 36
burst2 present	53 (98%) *total* 54	65 (92%) *total* 72

[Table II. Frequency of occurrence of release bursts (ejectives)]

The release burst of the second member of the cluster, [k'], is most often missing in word-medial clusters ([ʧ'k' ts'k' t'k']). In all of the six tokens where the burst is absent, [k'] is realised as a glottal stop.

The crucial result is the presence of the first release burst, seen in both clusters and sequences, voiced and aspirated. As noted by Robins & Waterson (1952), aspiration and glottalisation are seen in each consonant, for all six speakers. I show below representative waveforms and spectrograms of the relevant tokens.

In the word [dgoma] 'standing', two bursts are clearly visible in the waveform and spectrogram in Fig. 3. Word-medial clusters also have two distinct release bursts, as shown above in Fig. 2.

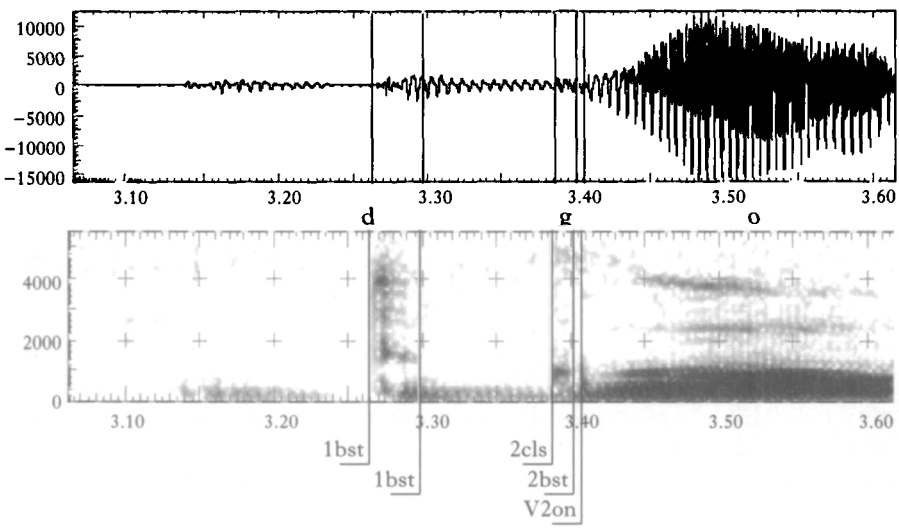


Figure 3
Waveform and spectrogram of part of [dgoma] 'standing' (speaker NL).

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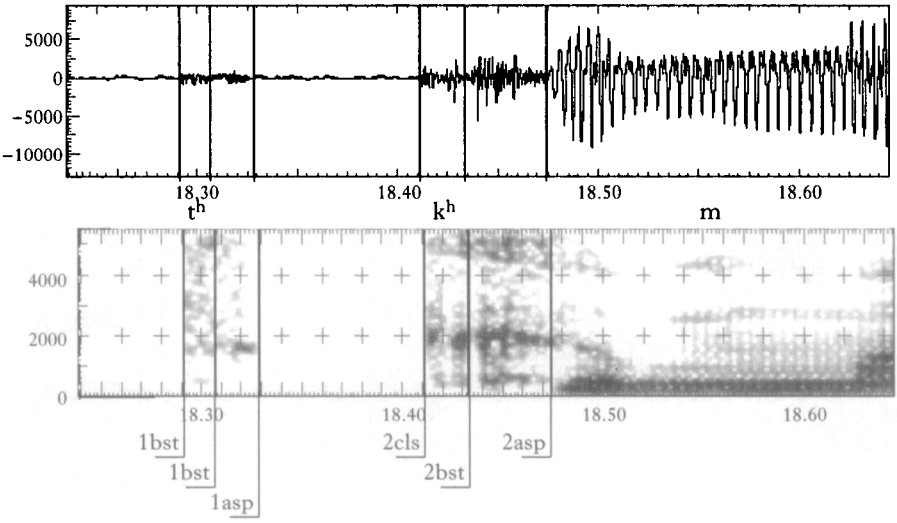


Figure 4
Waveform and spectrogram of part of [t^hk^hma] 'saying' (speaker NL).

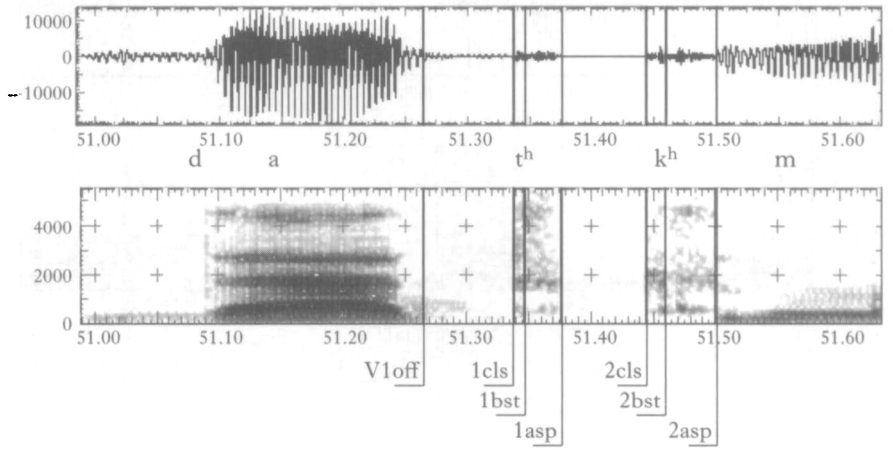


Figure 5
Waveform and spectrogram of part of [dat^hk^hma] 'to agree' (speaker NL).

Figures 4 and 5 show the words [t^hk^hma] 'saying' and [dat^hk^hma] 'to agree', with an aspirated release for each stop, word-initially and word-medially. Most tokens show clear portions of aspiration following each stop.

In Fig. 6 the release burst of word-final [d] of [sad gip'ovo] 'where do

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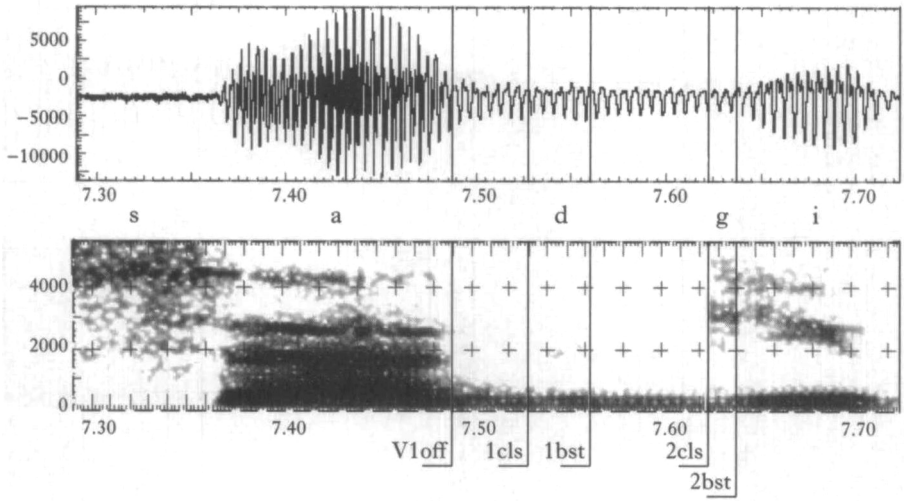


Figure 6
Waveform and spectrogram of part of [sad gip'ovo] 'where do I find you?' (speaker NL).

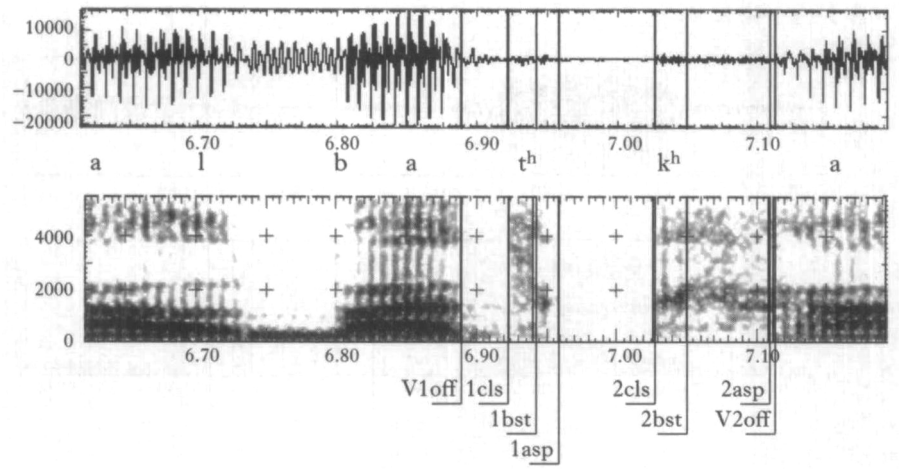


Figure 7
Waveform and spectrogram of part of [albatʰ kʰari] 'probably wind' (speaker DB).

I find you?' is quite weak, not clearly visible on the spectrogram. This is representative of some of the voiced consonant sequences. Similarly, in a sequence of aspirated stops shown in Fig. 7, [albatʰ kʰari] 'probably wind', the aspiration of the word-final [tʰ] release is visible, but shorter in duration than that of the word-initial [kʰ] release.

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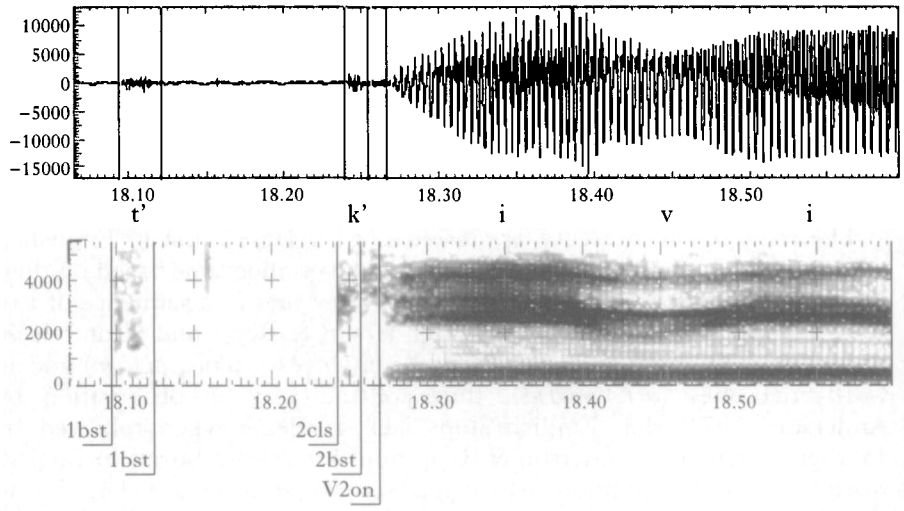


Figure 8
Waveform and spectrogram of part of [t'k'ivili] 'pain' (speaker NL).

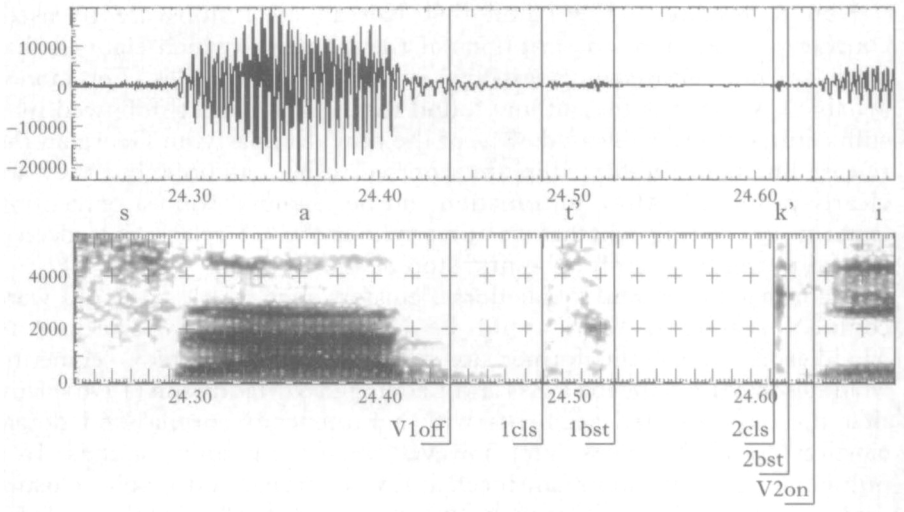


Figure 9
Waveform and spectrogram of part of [sat'k'ivari] 'worry' (speaker NL).

Two distinct release bursts are present in the ejective cluster [t'k'], both word-initially (Fig. 8) and word-medially (Fig. 9).

Thus, contrary to previous claims and predictions based on these claims, the figures clearly show the presence of two release bursts in

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the voiced clusters, one for each stop, of two aspirated release bursts in the aspirated clusters, and of two glottalised release bursts in the ejective clusters. The waveforms and spectrograms of these clusters show a clear sequence *closure1–burst1–closure2–burst2*, which contradicts the characterisation of harmonic clusters as having simultaneous closures and only one release. Both stops are released, and for the aspirated series both are aspirated.

The issue of the presence *vs.* absence of a release burst in English is addressed by Henderson & Repp (1982). The oscillograms based on their recordings contradict the commonly held view that in a sequence of two stops the first one has no release. Henderson & Repp find clear release bursts for both stops in word-internal sequences (*cactus*, *pigpen*) and in word-final ones (*act*, *sobbed*), thus contradicting an observation by Anderson (1974) that English stops lack a release when followed by another obstruent. Henderson & Repp find that release bursts in English words are most common when the second stop is a velar. In an alveolar–velar sequence both stops are released, explained by the fact that the same articulator is involved (the tongue). The first closure must be released before the second one can be formed. At the same time, the results of a perception experiment reveal that the burst is so weak that it is not heard. The authors therefore conclude that 'unreleased' is an auditory concept, but that a burst is acoustically and articulatorily present.

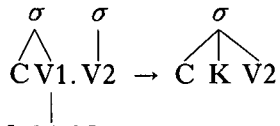
Kim & Jongman (1996) find that Korean coda stops are released, contrary to traditional descriptions of the language, which claimed that stops are not released in word-final or word-medial codas. For monosyllabic CVC words the authors found that a root-final [t] followed by a suffix-initial [k] was released 83 % of the time. Similarly, in Georgian the release bursts of the first stop are reported to be inaudible, but they are clearly produced. More information can be obtained from a perception experiment, testing whether the presence of the C1 release is indeed a crucial perceptual cue for the first stop of the cluster.

If coronal–dorsal and labial–dorsal clusters such as [dg tk bg pk] were complex segments, they would be similar to clicks. According to Maddieson (1990), the former are not attested as complex segments. Maddieson & Ladefoged (1989) and Ladefoged & Maddieson (1996) claim that the only attested segments with simultaneous coronal and dorsal closures are clicks. These are, however, velaric ingressive sounds. In a pulmonic egressive airstream mechanism, a coronal and a velar closure cannot be formed simultaneously. In the case of [pk tk bg dg], any front closure, whether labial or coronal, must be released before the velar closure can be formed. The two closures cannot be simultaneous, with only one release. We are dealing then with a sequence of two stops.

A case where apparent complex consonants are found to be sequences of segments is that of Shona (Maddieson 1990). Shona has a velarisation rule by which a glide following a non-velar consonant becomes a velar consonant. The rule is illustrated below:

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(10) *Shona consonant velarisation* (Maddieson 1990)



within stems

imbwa	→ imbgá	'dog'
uzutwe	→ uzútk^{w}e	'type of mushroom'

noun class prefixes /mu-/, /tu-/ + *stem*

mu + ana	→ mwana	→ mŋana	'child'
mu + edzi	→ mwedzi	→ mŋedzi	'moon'
tu + ana	→ twana	→ tk^{w}ana	'little children'

Doke (1931, cited in Maddieson 1990) refers to them as 'velarised' bilabials and coronals, implying that they are functionally single consonants. His studies show diagrams based on palatograms and linguagrams of the articulatory position of these clusters, suggesting that they have simultaneous closures. Phonological arguments for the treatment of these clusters as single segments are presented by Sagey (1986, 1990), for both Shona and Kinyarwanda. The main argument comes from syllable structure. The claim is that Shona allows only simple onsets, therefore any complex clusters occurring in onsets must be single segments.

The waveforms presented in Maddieson's study, however, clearly show that each stop has its own release burst. Measurements of intra-oral air pressure between the alveolar and the velar closures show that pressure falls before the velar release. This result constitutes further evidence that the two clusters do not overlap at all, but are successive. Moreover, only the second segment (the velar release) is labialised.

Based on these results, Maddieson argues that the velarisation rule is simply a glide-strengthening rule which changes glides into velar consonants when they follow non-velar consonants. He proposes that Shona clusters resulting from velarisation should be analysed as complex onsets, rather than complex segments. Their only special property is homogeneity of laryngeal features, which is also a property of the Georgian harmonic clusters. As pointed out by Maddieson, however, laryngeal homogeneity is commonly found in onsets, and does not necessarily indicate that the homogeneous cluster is a single segment.

Georgian might constitute a case similar to Shona. The acoustic evidence presented here shows that they are clearly not single segments. Thus, pulmonic egressive segments with simultaneous coronal and velar articulations continue to be unattested, in accordance with Maddieson & Ladefoged's prediction (1989).

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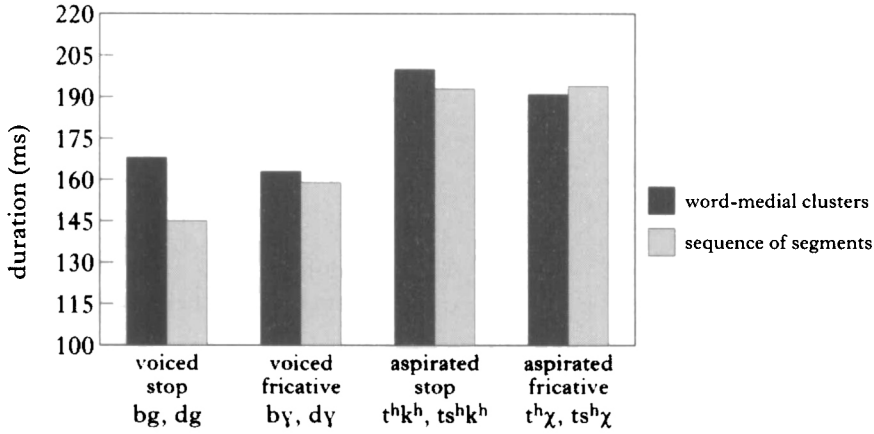


Figure 10
Average duration (ms) over all speakers of clusters *vs.* sequences as a function of the manner of the second consonant.

5.2 Secondary results: duration

We saw in the previous section that the claim according to which harmonic clusters have only one closure and one release is not supported by acoustic data. Assuming that there is a relationship between phonetic duration and timing slots, the representations in (7a) and (7b) also make predictions concerning phonetic durations. Since complex segments occupy only one timing slot, they are predicted to be shorter than sequences of two consonants, which occupy two timing slots. To test this prediction, I compared the total duration of clusters and sequences, in spite of the limitations imposed by the absence of good minimal pairs, and of a frame sentence in the recordings.

I compared the total duration of word-medial harmonic clusters to that of consonant sequences, measured from the offset of the vowel preceding the cluster/sequence (V1off) to the onset of the vowel following the cluster/sequence (V2on). None of the clusters turned out to be shorter than the sequences. The voiced clusters and the aspirated clusters were measured separately. The stop-final clusters ([dg bg t^hk^h ts^h k^h]) were separated from the fricative-final ones ([dɣ bɣ $t^h\chi$ $ts^h\chi$]). Figure 10 compares the average duration of word-medial clusters and of sequences formed across a word boundary (means based on three repetitions per speaker).

The only significant difference is found in the voiced stop + stop tokens. The word-medial 'harmonic clusters' were found to be significantly longer than the sequences. Paired two-tailed t-tests reveal a statistically significant difference between voiced word-medial stop-final clusters (mean: 166 ms) and sequences (mean: 140 ms), with the clusters being significantly longer ($t(11) = 4{\cdot}79$, $p = 0{\cdot}001$), and not the sequences,

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	word-medial cluster		*sequence*	
dg, bg	166	SD = 14·587	140	SD = 29·895
dɣ, bɣ	159	SD = 25·486	154	SD = 26·087
t^hk^h, ts^hk^h	201	SD = 22·832	195	SD = 19·884
$t^hχ$, $ts^hχ$	192	SD = 29·494	196	SD = 29·901

[Table III. Average duration of word-medial clusters *vs.* sequences of segments (ms)]

as would be predicted. For this series a significant difference was found for three of the six speakers, two male and one female: DB $t(11) = 4·14$, $p = 0·002$; GG $t(11) = 2·62$, $p = 0·024$; TS $t(11) = 2·91$, $p = 0·000$.

For the remaining three series the difference in duration is not statistically significant. The results are summarised in Table III.

If the word-medial clusters were indeed complex segments, they would be expected to be shorter than a sequence of two simple segments, yet this is not the case. Moreover, in one instance in the voiced series the harmonic clusters are slightly longer than the sequences. An analysis of the clusters as complex segments is not supported by these findings.

The clusters and sequences ending in a voiced stop were further segmented into separate parts (namely release burst, closure and fricative portion), which were measured individually, in an attempt to see which portion contributed to the difference. No significant difference was found in the duration of the second closure, of the release bursts or of the fricatives [ɣ χ]. The duration of the first closure did show a significant difference in voiced and aspirated clusters *vs.* sequences. The closure of the first stop turned out to be longer in the clusters than in the sequences. Table IV contains the average duration of the closure of the first stop in voiced and aspirated word-medial clusters and in stop sequences. The difference between them is statistically significant for both stop-final [dg bg t^hk^h ts^hk^h] and fricative-final tokens [dɣ bɣ $t^hχ$ $ts^hχ$], showing that the closure duration is longer in word-medial clusters than in stop sequences.

	word-medial cluster	*sequence*	
stop-final	50	40	$t(59) = 4·63$ $p = ·000$
fricative-final	57	43	$t(25) = 2·77$ $p = ·01$

[Table IV. Average duration of the closure of the first stop in voiced and aspirated stop-final and fricative-final clusters and sequences (ms)]

Obviously, these results are not entirely reliable, because of the lack of control for other factors which may have affected duration. However, supposing the same results were obtained in a controlled setting, the

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shorter duration of the sequence may indicate a difference in syllabification in the two environments. If both stops in the word-medial cluster are in the onset, then a longer closure may be needed for the pressure build-up required for a strong release of a preconsonantal stop.

So far, the occurrence of the release burst and the secondary results from total duration contradict the claim that harmonic clusters are single segments. Instead of showing only one final release burst, word-initial and word-medial harmonic clusters have two clear release bursts, one after each stop closure. Instead of being shorter than the sequences of segments formed across a word boundary, word-medial clusters turn out to be significantly longer in one series, and comparable in all others. Their longer than expected duration is due to the first closure portion. No significant difference was found for the remaining portions (second closure or burst duration).

Based on the results of the acoustic study, property (6e), simultaneity of closure and single release, can be eliminated from the list of properties characterising harmonic clusters.

6 Conclusions and further study

This study shows the importance of taking into consideration acoustic information, which allowed us to revise a particular phonological analysis. It has provided acoustic evidence for the nature of Georgian harmonic clusters. The results do not support the proposed phonological treatment of harmonic clusters as complex segments, but support instead their status as sequences of segments. The main piece of evidence is the presence of a closure and a release for each member of the cluster.

Additional evidence is found in duration differences. Georgian word-medial harmonic clusters turn out to be as long as consonant sequences formed across word boundary. In one case they are even slightly longer. If they were complex segments, they would be expected to be shorter than the sequences. The duration measurements, however, need to be repeated in a controlled setting. Based on the results of the acoustic study, I conclude that all obstruent clusters in Georgian are sequences of independently articulated segments.

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