Georgian harmonic clusters as complex segments?

A perceptual experiment

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1. Introduction

Harmonic clusters in Georgian consist of two obstruents, the first being a coronal or a labial and the second being a dorsal. The obstruents share the voicing characteristics. There are two types of harmonic clusters, referred to as type A and type B. Type A refers to the combinations of [−dorsal] stops, affricates and fricatives with [+dorsal] stops /g k k'/ and type B refers to the combinations of [−dorsal] stops, affricates and fricatives with [+dorsal] fricatives /γ x χ'/.[1] In some studies (Marr 1925; Machavariani 1965), the combinations of fricatives /s š/ with dorsal obstruents are also treated as harmonic clusters:

(1)

Type A (C + stop)			Type B (C + fricative)		
[+voi]	[−voi]	[glot]	[+voi]	[−voi]	[+glot]
bg	pk	p'k'	bγ	px	p'χ'
dg	tk	t'k'	dγ	tx	t'χ'
jg	ck	c'k'	jγ	cx	c'χ'
ǰg	čk	č'k'	ǰγ	čx	č'χ'
zg	sk		zγ	sx	
žg	šk		žγ	šx	

While investigating the special behaviour of Georgian harmonic clusters, several phonological arguments have been proposed to support their analysis as complex

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segments. Some of them are considered below:

- Harmonic clusters always syllabify together intervocalically, while other obstruent clusters are never tautosyllabic, e.g. *si**t'χ'**va* 'word' [si.**t'χ'**va], *ce**cx**li* 'fire' [ce.**cx**li] (Axvlediani 1949; Žgenti 1956).
- Studies on the phonological processes involving consonant clusters revealed that in case one consonant of a harmonic cluster changes, then the other member changes as well, i.e., the processes shown in (2) are not attested (Dzidzishvili 1966). Rather, one harmonic cluster changes into another harmonic cluster, e.g. the alternation dg ~ tk: *c'ar**dg**ra* ~ *c'ar**tk**ra*, etc.[2]

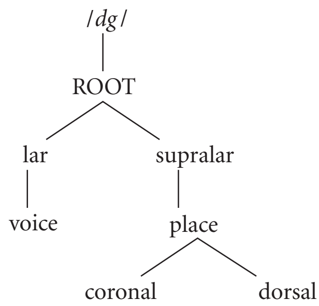
(2)	*dg	tg	*tk	dk
		dk		tg

- Consonant complexes, other than harmonic clusters, are characterized by optional /r/-insertion (Vogt 1958; Chikobava 1971; Deprez 1988).
- Harmonic clusters never occur across morpheme boundaries. Harmonic groups always belong to one morpheme, more specifically to the lexical morpheme, which is called the stem.
- Harmonic groups are the only obstruent sequences to appear in stem-final position (Vogt 1961; Deprez 1988).
- In reduplicated forms, harmonic clusters retain their complexity, e.g. *čkar-čkara* 'quickly'; *cxel-cxeli* 'hot'. Usually other types of obstruent sequences do not participate in the reduplication process. Exceptions to this generalisation are clusters of the /s/+C type, e.g. *sc'or-sc'ori* 'right', or *svel-sveli* 'wet'.
- Harmonic clusters are present in all Kartvelian languages (Svan, Megrelian and Laz). There are many examples of correspondences of harmonic clusters in Kartvelian languages, where the unity of the cluster is retained, e.g.

(3)	Georgian	Megrelian	Laz	Gloss
	ma**t'χ'**l-	mon**t'χ'**or-	mon**t'k'**or	'wool'

In addition to phonological evidence, phonetic claims about simultaneity of closure and release in harmonic clusters advocated by Žgenti (1965) and Aronson (1982) led Deprez (1988) to the conclusion that harmonic clusters should be treated as complex segments, represented as consisting of one root node as shown in (4):[3]

(4)



In line with Deprez' analysis, Chitoran (1998) argues that if harmonic clusters are complex segments, their articulatory gestures should overlap in time. As a result, the release burst of the first member of the cluster is suppressed by the occlusion phase of the second member of the pair, so that only the release burst of the second stop should come to the surface. Also, due to the (partial) temporal overlap of the two stops in the harmonic cluster, the duration of the complex segment should be shorter than that of the corresponding (heterosyllabic) sequence of consonants. Unexpectedly, there was no significant difference in frequency of occurrence of release bursts of the first and second stops in the two types of clusters; in fact, bursts were realised in more than 90 per cent of the cases, regardless of the type of cluster. Secondly, the duration of the harmonic clusters was not shorter than that of the corresponding C#C sequences; moreover, if there were significant duration differences, they were in the unexpected direction.

It should be pointed out that just counting the presence or absence of release bursts is a very crude measure. We found that C1 bursts in the complex segment were always present but had shorter durations and/or weaker intensities than their counterparts in heterosyllabic sequences (Butskhrikidze 1998). This 'incomplete suppression' of the C1 burst is hard to reconcile with the notion of gestural overlap, but does argue for a different status of harmonic groups as opposed to C+C sequences. Also, the phonological environments in which the harmonic clusters and their corresponding C+C sequences were examined, were not held constant in Chitoran (1998). Therefore, the issue is as yet unsettled. The present paper is yet another attempt to ascertain the phonological status of harmonic clusters as complex segments.

Alternative approach

We tested the phonological hypothesis of harmonic clusters as complex segments by looking at perceptual cues of native speakers of Georgian. The goal of our experiment was to show whether harmonic clusters have perceptual cues different from other types of consonant sequences, but similar to simplex segments. The task of the experiment was the detection of a CVC target embedded in three different types of non-word contexts: harmonic cluster (CV.CcV…), unrelated sequence (CVC.CV…), and single consonant (CV.CV….). The dot between V and C represents a phonetic syllable boundary. Two dependent variables were used to evaluate the experimental results, viz. detection rate (hit rate in %) and detection latency (reaction time in ms).

If harmonic clusters are indeed complex segments, it should be difficult to detect a CVC target embedded within a CV.CcV… context. This is because the final C in the target string occurs in the onset of the next syllable and is (arguably) part of a single phonological segment (i.e., a harmonic cluster). Consequently, in terms of the two dependent variables, hit rates should be poor while reaction times (for correct decisions) should be high.

Detection of the CVC target should be easy (high hit rates and fast latencies) if the final C of the target is in the coda position of the test string, i.e., if the stimulus string has the structure CVC.C…. This situation should arise when the target is embedded in an unrelated consonant string context (CVC.C…).

An intermediate degree of difficulty is predicted for the detection of the CVC target in a stimulus string where the final C of the target appears as a single consonant in the onset of the next syllable. The detection is relatively difficult because the listener has to resyllabify the final C, but less difficult than in the case of a harmonic cluster, as no decomposition of the cluster is required.

For instance, the target *k'ab*, should be maximally easy to detect in the stimulus string *k'ab.ra.na* (final *b* is in coda position), most difficult to detect in *k'a.bga.na* (final *b* is part of a complex cluster in the onset of the following syllable), and intermediate in *k'a.ba.na* (final *b* is a single C in the next onset).

2. Method

2.1 Stimuli

Targets were always sequences of the CVC type embedded in different phonetic contexts. Thirty-two sets (corresponding to the number of harmonic clusters, cf. (1)) were designed, each containing six non-words.[4] Three non-words in each set were target bearing, as follows:

i. one containing a harmonic cluster (harmonic Cc),
ii. one containing the consonant string (unrelated CC), the first segment of which was identical with the beginning of the harmonic cluster,
iii. one containing just the first segment of the harmonic cluster (single C).

The other three non-words in the set did not contain the target. For instance, in the case of the target *tab* the set of six non-words was *ta.bga.mi* – *tab.ra.mi* – *ta.ba.mi* – *ta.ra.mi* – *da.ra.mi* – *ča.ra.mi*. The full set of targets plus non-words is included in Appendix 1.

In all, 192 non-words (32 sets × 6 non-words) were recorded on Digital Audio Tape (DAT) by a female native speaker of Standard Georgian (the first author of the present paper) in a sound-proofed recording booth, using a Sennheiser MKH416 unidirectional condenser microphone. The recordings were then transferred to computer disk, downsampled to 16 kHz, edited out by means of a high-resolution waveform editor (Praat software, Boersma and Weenink 1996) and stored on disk.

2.2 Listeners

A total of 24 native Georgian listeners (15 female and 9 male) participated in the experiment. Subjects' ages ranged from 18 to 40. None of the subjects reported any speech or hearing impairment. All subjects took part on a voluntary basis and received no remuneration for their service.

2.3 Procedure

Subjects participated in the experiment in individual sessions. During the experiment the listener was seated in a quiet (but not sound-treated) room, with no other persons present. Subjects were instructed, interactively and in writing, to monitor the non-words that would be presented to them, and to decide for each non-word, as fast as they comfortably could while avoiding errors, whether it did or did not contain a pre-specified CVC sequence. If the stimulus contained the target sequence, the subject was to press a green key on the keyboard of a notebook computer with his right hand; if the non-word did not contain the target sequence, the subject was to press a red key with his left hand.[5]

The subject first heard a target (CVC sequence), followed by a 500-ms pause, which in turn was followed by a non-word. A 2000-ms timeout interval followed the stimulus. If the subject responded before 2000 ms had elapsed, the presentation of the next target was initiated 100 ms after the issuing of the response. If the no key was pressed, the next target was presented immediately after the 2000-ms time out.

The 192 target-non-word combinations were presented without any break, preceded by eight practice sequences. A different random order of presentation was used for each listener. Stimuli were converted from digital to analog on a notebook computer and presented to the listeners over good quality headphones. Stimulus presentation and response collection were fully automated, using E-prime software.[6]

3. Results

In total 24 (subjects) × 192 (stimuli) = 4,608 responses were collected. Only responses to target-bearing stimuli were statistically analysed, reducing the nominal number of responses to 2,304. Hit rate and mean latencies (for hits only) were computed and subjected to oneway analyses of variance (ANOVA) with consonant type (harmonic Cc, unrelated CC, single C) as a fixed effect. Post hoc t-tests for contrasts between pairs of consonant types were run if the overall effect was significant. We will first present the results for the dependent variable 'hit rate', and then proceed with the 'latency' data. Finally, the data will be analysed a second time, after selecting a specific, phonologically (distributionally) motivated, subset with coronal stops and affricates only.

3.1 Hit rate

Table 1 presents means and standard deviations for the dependent variable 'hit rate' broken down by the three types of consonant sequences.

Table 1. Mean hit rate (%) and standard deviation broken down by type of stimulus sequence

Type of stimulus sequence	Mean	SD	N
Unrelated (CC)	86	35	754
Single (C)	78	41	748
Harmonic cluster (Cc)	80	40	748

Table 1 shows that the CVC target was correctly detected in stimuli where the target was an integral syllable (unrelated CC, i.e. the easiest condition) in 86 percent of the cases. The hit rate is substantially poorer (80%) in the harmonic cluster (Cc) context, which is as predicted. However, the hit rate in the single consonant (C) context, which we predicted to assume an intermediate position along the difficulty scale, was poorer still (78%). The overall effect is significant, $F(2,2247) = 6.8$ ($p = .001$). The post hoc tests reveal that unrelated CC differs from the other two types, which do not differ from one another.

Several studies have claimed a difference within harmonic groups on distributional grounds: coronal + dorsal versus labial + dorsal (Vogt 1958; Chikobava 1971; Deprez 1988). Coronal + dorsal harmonic groups may be part of three-member clusters while labial + dorsal harmonics may not. Secondly, coronal + dorsal harmonic groups participate in long consonant sequences while the labial +

dorsal type does not. On the basis of these distributional criteria, Deprez (1988) proposed that all coronal + dorsal harmonic groups should be treated as complex segments, whilst the labial + dorsal type should be analysed as either true (CC) clusters or as complex (Cc) segments, based on some lexical distinction.

Since all our stimuli are non-words, there is no way of knowing which labial + dorsal Cc clusters should be analysed as true CC clusters. Therefore we reran the analysis after selecting only responses to stimuli that contained the coronal-dorsal type (for which the predictions are clear cut). To be on the safe side, we also excluded the harmonic types that began with a continuant; these seem to pattern with the labial + dorsal type. As a result of this data selection, only the types contained in rows 2, 3 and 4 in (1) were kept in the analysis. This left us with 18 harmonic clusters (instead of 32) and 54 stimuli. Table 2 presents the breakdown of results.

Table 2. Mean hit rate (%) and standard deviation broken down by type of stimulus sequence. Only cluster types with coronal stops and affricates were selected

Type of stimulus sequence)	Mean	SD	N
Unrelated (CC)	86	35	446
Single (C)	74	44	442
Harmonic cluster (Cc)	75	34	443

The results are qualitatively the same as in Table 1, but the scores for the harmonic clusters (Cc) and those of the single consonants have dropped a few points, so that they differ more from the unrelated C+C sequences. Consequently, the overall effect is more strongly significant, $F(2,1328) = 10.7$ ($p < .001$). CC differs from both Cc and C, which do not differ from each other.

We conclude that separating out the coronal obstruent cases does not substantially change the effects. Therefore, there seems no firm experimental support for the claim that complex segment status only applies to coronal obstruent clusters.

3.2 Reaction time

Table 3 presents mean detection time (in milliseconds) for hits only, broken down by type of cluster. Detection time was defined as the time interval between the onset of the stimulus sequence and the moment the listener pressed the response key.

The results indicate that the target was detected somewhat faster in the single C condition than in the other two conditions, which do not seem to differ from each other. However, the effect is a trend at best, as the ANOVA just fails to reach significance, $F(2,1829) = 2.7$, $p = 0.067$ (ins.).

Table 3. Mean and standard deviation of target detection time (ms) for hits only, measured from the stimulus onset, broken down by type of stimulus sequence

Type of stimulus sequence	Mean	SD	N
Unrelated (CC)	1041	354	645
Single (C)	1007	335	587
Harmonic cluster (Cc)	1052	362	600

Of course, the listener can only detect the target once the third segment in the stimulus sequence has become available. Since there may well be a difference in temporal structure between the three types of stimuli, we redefined the detection time as starting from the earliest moment in the acoustic signal of the stimulus that fully contained the CVC sequence specified by the target. That is to say, the reaction time was measured from the offset of the first (or only) consonant in the crucial sequence. The results for the corrected detection times are presented in Table 4.

Table 4. Mean and standard deviation of target detection time (ms) for hits only, measured from the offset of C1 in stimulus, broken down by type of stimulus sequence

Type of stimulus sequence	Mean	SD	N
Unrelated (CC)	894	389	645
Single (C)	844	372	587
Harmonic cluster (Cc)	892	407	600

The results are qualitatively the same as before, but the difference between the relatively fast detection time for the single C condition and the remaining two has increased to about 50 ms, and reaches significance, $F(2,1829)=3.2$, $p=0.042$. Single C differs significantly from the other conditions, which do not differ from each other (Scheffé test).

On the basis of Table 4 then, we conclude that the harmonic clusters pattern with the unrelated CC sequences. This patterning is different from that found in the results for hit rate (Tables 1 and 2).

3.3 Summary of results

Table 5 summarizes the results of the experiment in terms of relative degree of ease with which the CVC target was detected in the stimuli, broken down by the three types of stimulus sequence. In Table 5 '+' stands for 'relatively easy detection', whilst '–' represents 'relatively difficult detection'. Of course, easy detection corresponds with a high percentage of correct detections, but with low detection times.

Table 5. Relative ease '+' versus difficulty '–' for hit rate and detection time, broken down by stimulus type

Stimulus sequence **Dependent**	**Unrelated CC**	**Harmonic Cc**	**Single C**
Hit rate (%)	+	–	–
Detection time (ms)	–	–	+

The summary in Table 5 shows quite clearly that the harmonic Cc clusters behave like single consonants in terms of hit rate, but as a sequence of two unrelated consonants when it comes to detection time. We interpret this patterning as an indication that harmonic clusters are neither true consonant sequences nor simplex consonants. They have separate, intermediate, status in the phonology of Georgian.

Also, Table 5 indicates that detection of a CVC sequence was always difficult in a harmonic cluster context. Probably, this very patterns shows that harmonic clusters are indeed complex segments, perceived indeed as a unit by Georgian native listeners.

4. Conclusion and discussion

In the introduction we presented rather simple and straightforward predictions regarding the detectability of a word-initial CVC target that was embedded in three types of stimulus contexts, viz. the single C condition (CV.CV…), the harmonic cluster condition (CV.CcV…), and the unrelated sequence condition (CVC.CV…).

We predicted that ease of detection would show up simultaneously in high detection rates (hit rates) and fast detection times (for hits). Moreover, we predicted that the target CVC would be most difficult to detect if the final consonant were the first part of a harmonic cluster in the onset of the second syllable in the stimulus string. The rationale behind this prediction was that the listener would have to break up a highly cohesive phonological unit, i.e. a complex segment, in order to match the target CVC with the stimulus string, and make the match in spite of a difference in syllable boundary.

Although high hit rates usually go together with fast detection time, this result did not obtain throughout our experiment. Yet, in the crucial condition, i.e. the complex segment condition, we did find the predicted correlation between poor hit rate and long detection time. Moreover, the harmonic clusters were consistently found to be the most difficult type in the experiment, whether the results are expressed in terms of hit rate or in detection time. The reference conditions (CC and C) were easier to detect than the harmonic clusters in terms of either hit rate (unrelated CC) or detection time (single C). On the strength of this evidence we argue that our perception experiment has substantiated the phonological status of Georgian harmonic clusters as complex segments. Apparently, a perceptual technique such as target detection in nonsense strings may provide a useful diagnostic in the determination of the phonological status of some sound unit, when the study of speech production or acoustics yields undecided results.

Before any definitive conclusions, whether substantive or methodological, are to be drawn from our experiment, however, the experimental technique should be calibrated against a clear-cut set of contrasts between simplex versus complex segments. After all, one might argue that if the Georgian complex segments were truly single consonants in the mental representation of the listener, it is hard to understand how our experimental subjects were at all able to split them up into plosive plus velar obstruent parts. Although the task of matching the target string to a complex segment was more difficult, our subjects were still quite successful in accomplishing their task. It would make sense, therefore, to run a similar experiment in English, where the affricates /ǰ č/ constitute clear and undisputed examples of complex segments that should be analyzed as single units — relying on synchronic distributional criteria, phonological processes, their behavior in speech errors (affricates are always interchanged with single consonants, Fromkin 1971) as well as on their historical origin (Steriade 1989; van de Weijer 1996). As in Georgian, the 'components' of the English complex segments also occur as single consonants in the phonology of the language, so that the task of splitting the complex segment and matching the first component to a single stop, should be doable. We expect that the English results will be highly comparable to our Georgian data.

Notes

1. The Georgian fricative χ' is alternatively transcribed as a glottalised uvular stop q'. Impressionistically it combines properties of stop and fricative articulation; nevertheless it functions as a fricative.

2. Given that it is highly unusual across languages to have members in a CC sequence — even across a syllable boundary — to have opposed [voice] values, the argument presented here is not compelling; the facts can be explained as straightforward voicing assimilation. However, Georgian is different from most languages in that it regularly allows heterogeneous obstruent clusters differing in the voicing feature (Žgenti 1956).

3. Harmonic clusters are considered as complex segments in numerous studies (Gamkrelidze and Machavariani (1965), Deprez (1988), Bush (1997), Nepveu (1994).

4. Non-words were chosen for several reasons: to maintain sameness of the phonetic environment of a target, and to avoid morphological or word frequency effects.

5. In the Georgian educational system right-handedness is normative. Assuming that no natural differences between right-handed and left-handed subjects exist in this population, we decided not to instruct our subjects to use their preferred hand for positive responses.

6. The script for the experiment was written by Ing. Jos J. A. Pacilly of the Universiteit Leiden Phonetics Laboratory.

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Appendix 1. The full set of targets (bold) and stimuli (non-words)

1. k’a.bga.na	1. da.p’k’a.li	1. ta.bga.mi
2. k’ab.ra.na	2. dap’.ra.li	2. tab.ra.mi
3. k’a.ba.na	3. da.p’a.li	3. ta.ba.mi
4. ca.ba.na	4. ba.ta.li	4. ča.ra.mi
5. ma.sa.na	5. k’a.da.li	5. da.ra.mi
6. ba.ra.na	6. ra.da.li	6. ta.ra.mi
k’ab	**dap’**	**tab**
1. da.pki.nu	1. ca.pxi.li	1. ča.p’χ’a.ri
2. dap.ri.nu	2. cap.ri.li	2. čap’.la.ri
3. da.pi.nu	3. ca.pi.li	3. ča.p’a.ri
4. ta.ri.nu	4. pa.ni.li	4. da.p’a.li
5. da.k’i.nu	5. da.vi.li	5. sa.ra.li
6. da.di.nu	6. na.di.li	6. ša.ma.li
dap	**cap**	**čap’**
1. sa.dge.ri	1. da.tko.mi	1. la.t’k’a.ni
2. sad.le.ri	2. da.tro.mi	2. la.t’r.ni
3. sa.de.ri	3. da.to.mi	3. la.t’a.ni
4. va.de.ri	4. ga.so.mi	4. k’a.ja.ni
5. ga.me.ri	5. k’a.do.mi	5. ga.da.ni
6. ja.ne.ri	6. na.no.mi	6. sa.ca.ni
sad	**dat**	**lat’**
1. c’a.dg e.ri	1. na.txi.li	1. za.t’χ’a.di
2. c’ad.le.ro	2. nat.mi.li	2. zat’.ra.di
3. c’a.de.ri	3. na.ti.li	3. za.t’a.di
4. va.ge.ri	4. ša.di.ri	4. sa.ma.di
5. jàa.xe.ri	5. k’a.ci.li	5. ja.sa.di
6. sa.te.ri	6. ma.ni.li	6. k’a.sa.di
c’ad	**nat**	**zat’**
1. te.jgi.mo	1. k’a.cki.li	1. de.c’k’e.vi
2. tej.di.mo	2. k’ac.gi.li	2. dec.’de.vi
3. te.ji.mo	3. k’a.ci.li	3. de.c’e.vi
4. ge.ri.mo	4. da.ci.li	4. ge.xe.vi
5. se.di.mo	5. sa.ri.li	5. ne.ge.vi
6. le.ki.mo	6. ža.di.li	6. te.ge.vi
tej	**k’ac**	**dec’**

1. c’a.jg u.li 2. c’aj.nu.li 3. c’a.ju.li 4. da.su.li 5. da.c’u.li 6. da.zu.li **c’aj**	1. da.cxo.mi 2. dac.k’o.mi 3. da.co.mi 4. ga.do.mi 5. k’a.so.mi 6. la.do.mi **dac**	1. ve.c’χ’u.k’i 2. vec.’gu.k’i 3. ve.c’u.k’i 4. ge.du.k’i 5. se.xu.ki 6. ze.su.k’i **vec’**
1. ma.ǰgu.di 2. maǰ.ru.di 3. ma.ǰu.di 4. ga.ru.di 5. ja.χ’u.di 6. la.ku.di **maǰ**	1. se.č.ko.na 2. seč.lo.na 3. se.č.o.na 4. š.e.bo.na 5. ge.so.na 6. p’e.lo.na **seč**	1. jo.č’k’o.li 2. joč’.mo.li 3. jo.č’o.li 4. do.ro.li 5. p’o.so.li 6. do.do.li **joč**
1. ma.ǰga.li 2. maǰ.sa.li 3. ma.ǰa.li 4. na.ga.li 5. ka.la.li 6. da.za.li **maǰ**	1. la.čxa.di 2. lač.ma.di 3. la.ča.di 4. k’a.sa.di 5. pa.za.di 6. na.p’a.di **lač**	1. sa.č’χ’u.gi 2. sač’.ru.gi 3. sa.č’u.gi 4. da.cu.gi 5. va.nu.gi 6. la.su.gi **sač’**
1. be.zgu.sa 2. bez.ru.sa 3. be.zu.sa 4. je.gu.sa 5. de.bu.sa 6. le.mus.a **bez**	1. t’a.sko.ni 2. t’as.mo.ni 3. t’a.so.ni 4. da.xo.ni 5. ba.go.ni 6. ta.lo.ni **t’as**	1. ge.zgo.bi 2. gez.m o.bi 3. ge.zo.bi 4. se.do.bi 5. xe.bo.bi 6. le.do.bi **gez**
1. na.sxa.zi 2. nas.ma.zi 3. na.sa.zi 4. ma.la.zi 5. k’a.pa.zi 6. ja.ra.zi **nas**	1. ge.žgu.k’a 2. gež.du.k’a 3. ge.žu.k’a 4. de.xu.k’a 5. me.su.k’a 6. c’e.zu.k’a **gež**	1. be.ško.mi 2. beš.lo.mi 3. be.šo.mi 4. ge.so.mi 5. pe.do.mi 6. de.go.mi **beš**
1. za.žgu.lu 2. zaž.ku.lu 3. za.žu.lu 4. la.su.lu 5. χ’a.du.lu 6. ta.xu.lu **zaž**	1. χ’o.šxo.pi 2. χ’oš.mo.pi 3. χ’o.šo.pi 4. ro.k’o.pi 5. do.no.pi 6. p’o.go.pi **χ’oš**	