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Georgian Syllables, Uncentered?

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Abstract

Both sonority, via the Sonority Sequencing Principle (SSP), and timing, via the coupled oscillator model advanced within Articulatory Phonology (AP), have been invoked to define the syllable as a unit. Georgian presents challenges for both definitions. The irrelevance of the SSP for Georgian phonotactics is well documented, while it is unclear whether Georgian displays the AP-predicted timing pattern of syllable onsets, i.e., the c-center effect. We investigate the relationship between sonority shape and global timing in complex onsets in Georgian by the means of a series of Electromagnetic Articulography (EMA) experiments. We use two measures of global timing, i.e., rightward shift of prenuclear consonant gesture and c-center stability, both relative to an anchor point in the vowel. Contrary to predictions, neither measure supports a c-center effect for Georgian syllables. Coordination is not affected by sonority shape, although sonority is reflected in patterns of overlap. We discuss these results in relationship to the phonological and morphological profile of Georgian and suggest that the absence of the c-center effect is possible given Georgian's permissive phonotactics, and aids in the formation of morphologically complex words. Typological extensions of this account are made.

Index Terms: syllable structure, c-center effect, sonority sequencing, Georgian

1. Introduction

In this paper, we examine the relationship between the sonority shape of a complex onset and the timing of the onset as a unit relative to the nucleus in Georgian in order to better understand how space and time work together to delimit the syllable. Georgian is an ideal language to study because it permits complex onsets of any sonority shape involving up to seven consonants.

1.1. Sonority

Sonority-based principles, such as the Sonority Sequencing Principle (SSP) [1] and the Obligatory Contour Principle (OCP) [2] can be used to define syllable edges. Georgian's non-adherence to the SSP especially is well known, and the wide range of sonority shapes permitted in Georgian, including sonority falls with left-edge sonorants, provides an opportunity to systematically investigate the relationship between sonority and global timing.

Sonority is an abstract property of phonemes, of which the most reliable physical correlate is intensity [3]. Sonority can also be crudely correlated with degree of vocal tract openness, and in this way provides a more spatially oriented definition of the syllable. Previous research on Georgian shows a systematic relationship between sonority shape and overlap between

adjacent consonants [4], indicating that sonority is relevant to some degree for Georgian speakers even though the SSP is not relevant for the phonotactic patterns of Georgian.

1.2. Coupled oscillators

In Articulatory Phonology [5][6], gestures—the phonological primes—form and release constrictions in the vocal tract and are active during a specified interval. Activation of gestures is controlled by oscillators in different phasing relationships with one another. There are two types of phasing relationships: in-phase and anti-phase. In-phase coupling results in synchronous gestural onsets, and anti-phase coupling results in sequential gestural onsets. The coupled oscillator model [7][8] defines the syllable in temporal terms, as a unit arising from specific phasing relationships.

In the coupled oscillator model, oscillators triggering consonant (C) gestures in simplex onsets have an in-phase relationship with the oscillator triggering the nucleus vowel (V) gesture, and oscillators in simplex codas have an anti-phase relationship with the nucleus. Figures 1 below illustrates both of these relationships.

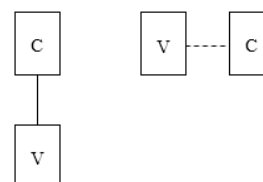


Figure 1. *In-phase (right) and anti-phase (left) oscillator coupling in simplex onsets and codas respectively.*

For simplex onsets and codas, this is straightforward. For complex codas as well, the ensuing pattern is straightforward. Coda C gestures are simply anti-phase with one another; they occur one after the other in sequence. In complex onsets a more complicated coordinative pattern arises. Each onset C gesture is in-phase with the V gesture, as shown in Figure 1, but then C gestures are in anti-phase coordination with each other. This is called competitive coupling and is illustrated in Figure 2.

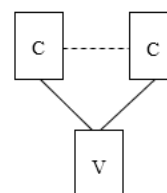


Figure 2. *Competitive coupling in complex onsets.*

Competitive coupling is the mechanism behind the c-center effect [9]. The c-center effect results in the rightward shift of the prenuclear C gesture relative to a simplex onset. The c-center itself is an abstract timepoint that is equidistant from all onset C gestures and in-phase with the V gesture.

In our research questions and hypotheses, we use the term *global timing*, consistent with the model’s proposal that the onset as a whole is a unit, and that regardless of the number of components, it is ultimately coordinated as a whole with respect to the nucleus. Our focus is not on the timing relationships between individual C gestures in the onset, but between the onset as part of the syllable and the nucleus.

1.3. Previous work on global timing in Georgian

Previous research on Georgian has found limited evidence for global coordination. In Goldstein et al. (2007), rightward shift of the prenuclear C gesture is found for one of two speakers [10]. Hermes et al. (2020) report rightward shift for onsets of up to three consonants but find that this process fails to occur in larger onsets [11]. To facilitate comparison with this work, we measured rightward shift as well. We also used a measure of c-center stability, detailed in section 2.3. This is the first time such an analysis has been conducted on Georgian.

1.4. Research questions (RQs) and hypotheses (Hs)

RQ1. What coordinative pattern is found in complex onsets in Georgian?

H1. Georgian will show the c-center effect, i.e., in-phase coordination between each onset C gesture and the nucleus V gesture, combined with anti-phase coordination between onset C gestures. This is the competitive coupling described in the coupled oscillator model [7][8].

RQ2. What is the relationship between sonority and global timing in complex syllable onsets in Georgian?

H2. Sonority and global timing are unrelated. From the perspective of a Georgian speaker, sonority is irrelevant for syllabification, so it should not affect global onset timing.

H3. Sonority and global timing are related. Rises will show the most prototypical c-center timing because they conform to sonority sequencing principles.

H4. Sonority and global timing are related. Falls will show the most prototypical c-center timing because previous research on Georgian [4] has shown that falls are the most overlapped sonority shape.

H5. The relationship between sonority and global timing will be reflected not in the actual timing measures themselves, but in the amount of variance found for each measure within each sonority shape. Rises will be the least variable sonority shape and falls the most variable. Plateaus will be an intermediate case.

2. Methods

In order to address the questions raised in 1.4 we used Electromagnetic Articulography (EMA) experiments. Data presented here are from three speakers, two female and one male in their twenties, all native speakers of Georgian.

2.1. Stimuli

Table 1 presents the test words. Participant F1, who was the pilot participant, produced a subset of these words using the

carrier phrase “____. *k’idev* ____ *vtkvi*.” (‘____. I said ____ again’). Participants F2 and M3 used the carrier phrase “____. *kalma* ____ *momts’era*” (‘____. ‘The woman wrote ____ to me.’). Our analyses included both the isolation and the quotative production.

Table 1: Test words (with English translation)

	C	CC	CCC
Sonority rise	dzala ‘strength’	dzmari ‘vinegar’	dzmriani ‘vinegary’
	mada ‘hunger’	mretsi ‘downward slope’	psma ‘peeing (n.)’
	rezi ‘Rezi (name)’	psalt’a ‘psalm’	sma ‘drinking (n.)’
	pandi ‘wrestling move’	pjavi ‘Pshavia (region)’	pjmuis ‘cow snorting’
Sonority plateau	sami ‘three’	jmagi ‘maniac’	
	javi ‘black’	t’eni ‘damp’	t’q’eba ‘lamenting (n.)’
Sonority fall	q’eli ‘throat’	q’debi ‘bindings’	t’q’deba ‘breaking (n.)’
	deba ‘placing (n.)’	msoplio ‘world’	msp’obeli ‘destroying’
	sopeli ‘village’	sp’oba ‘destroying (n.)’	
	p’ovna ‘finding (n.)’		

2.2. Data Acquisition

Data were collected using an Electromagnetic Articulograph AG501 (Carstens Medizinelektronik GmbH). Three sensors were attached to midsagittal points on the tongue (one on the tongue tip; two on the tongue body). Sensors were attached to the upper and lower lip, and to the lower incisor to track jaw movement. Reference sensors were attached to the upper incisor and to the nasion, and behind the mastoid processes for head correction. Audio data were recorded with a Shure SCM262 microphone mixer at a 16 kHz sampling rate, with a Sennheiser shotgun microphone positioned a foot away from the participant’s mouth. Kinematic data were automatically synchronized with the external audio data. Stimuli were presented in the Georgian orthography on a computer screen positioned approximately four feet from the participant.

2.3. Analysis

Data were semi-automatically labelled using custom software (Mark Tiede, Haskins Laboratories). The following timepoints for each consonant gesture in the onset were identified using velocity criteria: gestural onset; constriction achievement; constriction release; and gestural offset. The time of peak velocity for constriction formation and for release were also labelled. Figure 3 presents a schematic.

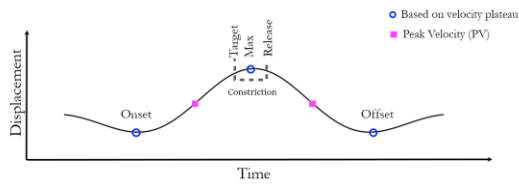


Figure 3. Timepoints labelled for each gesture

These timepoints were then used to compute the following measures: 1) C_n to anchor time, also known as rightward shift, and 2) c -center to anchor time. For both measures the anchor point was defined as the timepoint of maximum root mean square (RMS) value for the acoustic vowel, with the zero-crossing rate subtracted to remove interaction with frication. This represents the point at which the vocal tract is most open for the vowel and is correlated with the lip aperture movement that occurs during the vowel [11].

2.3.1. C_n to anchor time (rightward shift)

Rightward shift is often used as a proxy measure for the c -center effect [10][11][12][13]. The so-called shift is observed when comparing CV syllables to CCV and CCCV syllables; the larger the onset, the earlier the rightmost C gesture is initiated relative to the V gesture. To assess the presence of this shift, we measured the time from the onset of C_n to the anchor point as defined in the paragraph above.

2.3.2. c -center to anchor

As a more direct measure of global organization, we measured the time between the c -center itself and the anchor point defined above. We defined the c -center here using gestural onsets as opposed to midpoints [9], because the coupled oscillator model specifically makes predictions about the onset of gestures. We defined the c -center as the timepoint that is the average of the onset timepoints of each consonant. Then, we measured the distance from this c -center point to the anchor.

2.3.3. Statistical analysis

All data were analyzed using linear mixed effects models in R [14] with the lme4 package [15]. For each measure we began with the maximal fixed effects structure and used R's drop1 function to determine the final fixed effects structure. The following fixed effects were included: Size (C vs. CC vs. CCC); Sonority (Rise vs. Plateau vs. Fall); and Phrasal Position (Isolation vs. Quotative). We also began with a maximal random effects structure for each measure, which included: Speaker, Word, Trial, Vowel Quality, Pre-vocalic segment, and Post-vocalic segment. The final random effects structure was decided using rePCA [15] to avoid overfitting. Post-hoc pairwise comparisons were done using the emmeans package [16] with a Holm correction for multiple comparisons. Plots were made in R using the ggplot2 package [17].

3. Results

3.1. C_n to anchor

The final model for rightward shift had random intercepts by Speaker, Trial, and Word, and fixed effects of Size, Phrasal Position, and their interaction. Our data did not show evidence of the rightward shift associated with the c -center effect. This means that there was no significant effect of onset size on the

C_n to anchor distance. Sonority shape was also not significant. No within-phrasal position Size pairs were significantly different. There was a significant effect of phrasal position, which was the same across measures for all speakers: quotative productions were closer together in time than isolation productions. Figure 4 shows the C_n to anchor time for each onset size and phrasal position. Although the predicted effect was present as a non-significant trend in the isolation position, it was no longer present in the phrase-medial position.

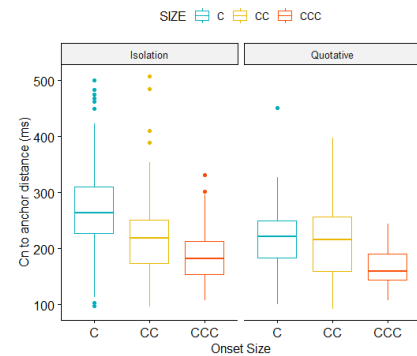


Figure 4: C_n to anchor distance across onset sizes and phrasal positions

Another set of analyses, not reported here due to space limitations, did not detect any effect of cluster size on the duration of the pre-nuclear C gesture. The difference between prosodic contexts could instead be due to prominence effects. In the isolation condition the test word is new information, but in the quotative it could be considered given information. Future research will address this question.

3.2. c -center to anchor

The final model had random intercepts by Speaker, Trial, and Word, and fixed effects of Size and Phrasal Position. As with the results for rightward shift, our measure of the c -center distance to anchor did not show the predicted pattern. Similar to the rightward shift measure, a significant difference between phrasal conditions was detected such that gestures in the isolation condition were further apart from one another.

C-CC and C-CCC onsets were significantly different from one another ($C < CC, CCC, p < 0.05$); after correction for multiple comparisons, the CC-CCC comparison was marginally significant ($CC < CCC, p = 0.07$). This is contrary to the prediction of the coupled oscillator model, as laid out in section 1.4. Under this model, the c -center should be invariant in its relationship to the anchor point regardless of onset size.

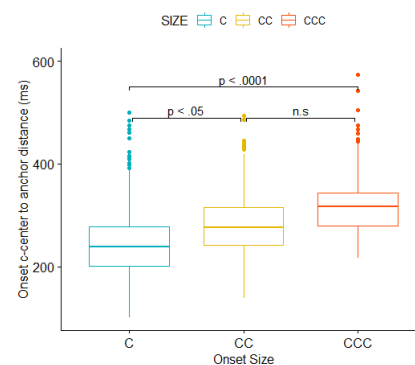


Figure 5. c -center to anchor distance by onset size

3.3. Timing variability

To assess the variability of each independent variable level for both measures, we used the interquartile range (IQR). Interquartile ranges are presented below for each measure by speaker and sonority shape.

Table 2 shows that our hypothesis regarding variability (H5) was not correct. Rises were the most variable sonority shape for both measures. This is likely a reflection of the wider range of prenuclear consonants in the test words in Rise condition. Additionally, intrusive vocoids are common in rises in our data (75 of 287 tokens, 26%). Vocoids are also found in sonority plateaus (44 of 73, or 60%), but the identity of the prenuclear consonant does not vary.

Table 2. *IQR values of interval duration (in ms) by sonority shape*

	Rise	Plateau	Fall
Cn to anchor	102	68	68
C-center to anchor	96	64	87

Table 3. *IQR values of interval duration (in ms) by speaker*

	F1	M1	F2
Cn to anchor	108	92	74
C-center to anchor	82	98	85

The Cn to anchor variability could be explained by the variety of consonants in the prenuclear position. The variability of the c-center to anchor measure may be the reflection of the complex relationship between sonority and overlap in Georgian [4] that was not found directly in either measure discussed above.

3.4. CV coordination

The coupled oscillator model also predicts in-phase coordination in a CV syllable. The measures reported here cannot be used to make claims about the vowel gesture directly, but we do see a wide range of Cn-to-anchor values in CV onsets (c.f. Figure 5), which suggests a less tight coupling relationship between C and V than assumed for other languages. Future work will examine CV coordination directly.

4. Discussion

Our results show that Georgian does not reliably show the timing pattern associated with a complex onset under the coupled oscillator model's assumptions, rejecting H1. The absence of the c-center effect has been found before, most notably in Tashlhyit Berber [10], where CCV sequences have a C.CV parse. This, of course, raises the question of whether or not CC(...)V sequences in Georgian are indeed monosyllabic. Multiple strands of evidence suggest that they are, and that the syllable is a relevant unit to which Georgian speakers are sensitive in production. Research on Georgian prosody [18][19] suggests that the syllable is a meaningful prosodic unit in Georgian. Articulatory research on Georgian [4] also suggests that speakers are sensitive to preserving a syllable parse when modulating overlap between adjacent consonants. Further

compelling evidence comes from poetry. Contemporary Georgian haiku [20][21] show that a) the syllable is a metrical unit that speakers are aware of, and b) that CC(...)V sequences are monosyllabic.

From this, two issues follow: 1) how *does* Georgian organized the syllable as a unit in production and 2) why does it not do so in ways previously observed in other languages. At this point, we can only speculate as to the first question, but we can identify several aspects of Georgian's structure than can address the second.

In Georgian, most first and second person marking is done through prefixing a -C- or -CC- morpheme on the root so this pattern is quite common. This means that syllable onsets can vary within the same lexical item. The absence of c-center coordination could facilitate the slotting-in of these morphemes. Other languages that have similar morphological systems—prefixing single consonants—might be expected to behave in a similar way. Georgian's permissive phonotactics may also play a role. Complex codas, especially monomorphemic ones, are rare, and there are essentially no restrictions on onsets. This means that no phonotactic violations arise when assigning multiple consonants to the onset, and no need to use timing to syllabify intervocalic consonant sequences in specific ways to avoid violations, as may be the case in languages with a more restricted set of possible onsets.

Our results also point to a more subtle relationship between sonority and articulatory timing than we hypothesized. As mentioned, previous work [4] has reported an effect of sonority on overlap, but we do not see an effect of sonority on global timing (being closer to H2 than H3 or H4). More work is needed to fully understand how overlap between adjacent gestures relates to the global patterns discussed here.

5. Conclusions

Our results suggest that syllable organization in Georgian cannot be explained by current models of syllable structure. Counter to predictions made by the coupled oscillator model of syllable structure [8], Georgian does not show global onset coordination and instead presents an uncentered syllable. This coordinative pattern is supported by and supports multiple aspects of Georgian structure, and we propose that languages with similar features may display similar timing patterns. Further work is needed to fully understand what exactly defines the syllable in production in Georgian.

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