Timing lag matters in the perception of Georgian stop sequences by native speakers
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It has been proposed that perceptual considerations are encoded in synchronic grammars (Hayes et al. 2004). We examine here the concept of perceptual recoverability, as used in Articulatory Phonology (AP) (Browman & Goldstein 1992, Goldstein & Fowler 2003) with respect to the relative timing of adjacent consonantal gestures. Although perceptual recoverability is not concretely implemented in AP, it is considered one of the factors that characterize intergestural coordination.

This study aims to test in perception the following specific hypothesis based on the perceptual recoverability of consonantal (C) gestures: gestures in a stop-stop sequence will exhibit less temporal overlap in contexts where C1 information may be harder to recover. Chitoran et al. (2002) found that consonant timing in Georgian stop sequences varies with position in the word and the order of place of articulation in the sequence. Word-initial sequences are significantly less overlapped than word-internal ones, and sequences with a back-to-front (B-F) order of constriction location (gd, tp) are less overlapped than sequences with a front-to-back order (F-B) (dg, pt). These differences were attributed to considerations of perceptual recoverability, but Chitoran & Goldstein (2006) found that stop and liquid combinations show the same place order effect, even though neither the stop nor the liquid is in danger of being obscured by a high degree of overlap. These latter findings thus weaken the perceptual recoverability account. In a recent, detailed production study of Greek, whose CC inventory approaches that of Georgian, Yip (2013) did not find conclusive evidence supporting perceptual recoverability.

In the present study, we test the perceptual recoverability hypothesis in two perception experiments with native listeners of Georgian. Perceptual responses from listeners are evaluated against a detailed acoustic and articulatory (EMA) analysis of the Georgian stimuli. The variation present in Georgian speech patterns was interpreted as speaker-controlled strategies for increasing C1 perceptibility in C1C2 contexts (Chitoran et al. 2002). The crucial elements of this variation are: longer lag, which would favor a clearer, audible C1 release in a stop sequence, and the presence of a C1 vocalic release, which would favor clearer C1 formant transitions. Based on these findings on production patterns, we test the following hypotheses: H1 Longer timing lag between C1 and C2 facilitates the recovery of C1 gestures; H2 C1 vocalic release facilitates recovery of C1 gestures.

28 Georgian native listeners were tested in Tbilisi, Georgia. One male Georgian native speaker produced Georgian words, containing C1C2 sequences in word-initial and medial position, B-F and F-B place order: e.g., gberavs, dagbera, bgera, abga. Articulatory (EMA) data were simultaneously collected. The stimuli were excised C1C2V portions, segmented on the acoustic signal from the midpoint of C1 closure to the midpoint of V. Some of the stimuli occasionally included C1 vocalic releases (C1 VC2). CVCV sequences (e.g., deba) were included as controls. All C1C2 stimuli and controls are attested word onsets in Georgian.

Experiment 1 was a forced choice identification task. The listeners identified each stimulus as beginning with either “cc” or “cv”. Results showed that Georgian listeners successfully identified the presence of two consonants 70% of the time. To better understand what happened when the listeners failed to recover the C1C2 sequences (e.g., whether they heard an epenthetic vowel or deleted one of the consonants), Experiment 2, a transcription test, was conducted a week later. The same participants heard subsets of the stimuli in Expt. 1 and transcribed them in Georgian orthography.

The results of Expt. 2 were analyzed in parallel with the analysis of the acoustic and articulatory properties of the stimuli. The acoustic parameters measured include: (a) the duration of the inter-burst interval (onset of C1 release burst to onset of C2 release burst) as a measure of Acoustic Lag; (b) the occurrence of vocalic releases; and (c) their duration, when present. Two articulatory measures of lag were examined, as distances between the following articulatory landmarks measured on the EMA signal: (d) C1 release onset to C2 release onset (Release Lag), and (e) C1 gesture onset to C2 gesture onset (Onset Lag). In Expt. 2, C1 is correctly transcribed 66% of the time. In this abstract, we focus on whether each of the five measures significantly contributes to correct identification of C1, and if so, whether the effect interacts with Place Order (B-F vs. F-B). The results were statistically analyzed using multiple logistic regressions. Due to colinearity among the measures, five separate models were constructed. Taken together, the results of these analyses support H1, but not H2.
Longer lag facilitates the recovery of C1. The three lag measures support H1, but differ in their interactions with place order (Fig.1 a,d,e). First, C1 was more correctly identified when Acoustic Lag was longer ($\beta$=0.017, $p<.001$). Neither the effect of Place Order nor the interaction Acoustic Lag*Place Order was significant. Release Lag contributes significantly to accurate identification of C1 ($\beta$=0.007, $p<.001$), along with a significant interaction Release Lag*Place Order ($\beta$=0.013, $p<.001$). Post-hoc tests within each place order revealed that longer Release Lag helped the recovery of C1 only in B-F sequences, but hindered it in F-B sequences ($p's<.001$). Onset Lag was a significant predictor for C1 identification ($\beta$=-0.004, $p<.05$), along with a significant interaction between Onset Lag*PlaceOrder ($\beta$=0.013, $p<.001$). Post-hoc tests revealed that longer Onset Lag facilitated accurate transcription of C1 only for F-B sequences ($p<.05$). For B-F sequences, the effect was not significant.

The presence of a vocalic release does not facilitate the recovery of C1. Neither the presence of a vocalic release nor its longer duration enhanced the recovery of C1 (Fig.1 b,c). The main effect of presence of a vocalic release on C1 identification was not significant. Furthermore, the duration of the vocalic releases, when present, actually inhibited the correct identification of C1 ($\beta$=-0.074, $p<.001$). The two measures did not significantly interact with Place Order.

Figure 1 (a-e): Five measures for the stimuli that induced correct C1 identification (white boxes and solid line) and those that did not (grey boxes and dashed line), for B-F and F-B sequences.

In sum, the current findings suggest that native Georgian listeners benefit from longer lag between C1 and C2 in recovering C1 in C1C2 sequences. Contrary to the hypothesis that C1 vocalic release with richer C1 formant transition information would help listeners recover C1, vocalic releases seem to be detrimental. If speakers produce vocalic releases for the listeners’ sake, their efforts are ineffective. However, the timing lag results do suggest that native Georgian listeners are sensitive to differences in timing lag. Moreover, listeners benefited from different articulatory lags in C1C2 sequences of different place orders: in a F-B sequence, longer Onset Lag was beneficial, while longer Release Lag helped in a B-F sequence. This finding, together with the previous findings for Georgian speakers (Chitoran et al., 2002), suggests that native speakers of Georgian time the two C gestures so as to allow successful recovery of C1. Arguably, speakers are also sensitive to place order. They time two C gestures in a F-B sequence relative to their onsets. This results in a moderate lag, but one that is sufficient for a F-B sequence in which C1 is released into an open vocal tract. In a B-F sequence, the gestures are timed relative to their releases, resulting in a longer lag, which is necessary for recovering C1 that is released into a constricted vocal tract.

Taken together, the results support the inclusion of timing lag rather than recoverability constraints in the phonological grammar. The different timing lags in B-F and F-B sequences may either result from online computation, or may be phonologized patterns whose historical development may have included recoverability considerations, but are now generalized to the phonological system. We argue for the latter interpretation, because it incorporates the behavior of stop/liquid combinations (Chitoran & Goldstein 2006) and the historical development of stop-step sequences in Georgian.