

Gestural reorganization under rate pressure interacts with learnedlanguage-specific phonotactics

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4pSCb18. Gestural reorganization under rate pressure interacts with learned language-specific phonotactics

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Studies of articulatory reorganization occurring under rate-driven production pressure can provide a window into speech planning. Previous work shows evidence for stable coordinative structures in speech in which VC patterns reorganize to CV, VCC to CCV, and coronal-labial to labial-coronal order. Such stable modes are argued to result from general physical-biological constraints imposed by the articulatory/auditory system. Here we examine whether stable modes can also arise from linguistic patterns learned on a language-specific basis. The case study is Georgian, which licenses complex onsets disregarding sonority, following instead a phasing pattern whereby degree of overlap varies with order of constriction location (front-to-back /pt/ sequences are more overlapped than back-to-front /tp/). We analyze preliminary data from native speakers repeating the Georgian words [pata] and [tapa] as they tracked an accelerating metronome. Results show: 1) pAta>patA>pta (stress shift followed by elision, licensed by Georgian phonotactics); 2) tApa>tAp (elision only; consistent with Georgian order constraints, not with biomechanical constraints). These patterns are contrasted with similar data from French in which elision is not observed, consistent with French phonotactics. The data thus provide an example in which language-specific structure rather than biomechanical constraints alone mediate gestural reorganization. [Work supported by Fulbright-Hays]

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Studies of articulatory reorganization occurring under rate-driven production pressure have shown that articulatory gestures reorganize in accelerated speech. These studies provide evidence for stable coordinative structures in which VC patterns reorganize to CV, VCC to CCV (Stetson 1951, Tuller & Kelso 1990, Gleason 1999), and coronal-labial to labial-coronal order (Rochet-Capellan & Schwartz 2007, Lancia & Fuchs 2011). Such stable modes are argued to result from general physical-biological constraints imposed by the articulatory/auditory system. Speech articulation, like other aspects of motor control, shows frequency-driven reorganization. For example, a 1:1 frequency ratio is preferred in syllables (e.g., alternating C and V, one jaw cycle per syllable).

In our study we examine whether stable modes can also arise from linguistic patterns learned on a language-specific basis. We test the hypothesis that rate-induced reorganization does not exclusively reflect general physical and biological constraints imposed by the articulatory and auditory system, but that under the right conditions, the reorganization can be mediated by constraints imposed by articulatory routines developed and learned on a language-specific basis. We specifically propose that the linguistically-relevant articulatory routines that will interfere with the emergence of intrinsically stable coordination modes are language-specific phonotactics and language-specific prosody.

We compare data from two languages – Georgian and French – that differ in their phonotactic and prosodic structure. Georgian licenses complex onsets that disregard sonority, following instead a phasing pattern whereby degree of overlap varies with order of constriction location: front-to-back /pt/ sequences are more overlapped than back-to-front /tp/ (Chitoran et al. 2002). We analyze preliminary data from native speakers repeating the Georgian words [pata], [tapa], and [paki], as they tracked an accelerating metronome. These patterns are contrasted with similar data from French. The preliminary results we present here show that different patterns of reorganization are obtained in the two languages. They are thus consistent with our hypothesis, suggesting that language-specific structure interferes with biomechanical constraints in mediating gestural reorganization. By comparing such cases of potentially competing effects of linguistic structure on default stable modes of coordination, we come closer to a full understanding of the interplay between bio-mechanical and cognitive factors in speech planning.

In section 1 we present the methodology of the study, followed by the discussion of the results in section 2. We present the qualitative analysis of the reorganization patterns observed for the following utterances: [pata] vs. [tapa] in Georgian (section 2.1), [pata] vs. [tapa] in French (section 2.2), [paki] in Georgian (section 2.3). Section 3 concludes the study.

Methodology

Fifteen native speakers of Georgian were recorded in Tbilisi, Georgia, in a quiet room at Tbilisi State University. Six native speakers of French were recorded in Lyon, France, under similar conditions. All participants were instructed to produce each word synchronized to the beat of an audible metronome, and to not stop during the production to take a breath or to correct themselves. The beat started at a constant rate, with a 600 ms interval between beats, then increased gradually, reaching a second plateau of 100 ms between beats. The duration of the accelerating portion between the beginning and ending plateaus was 8 seconds. The recordings were duplex, with the metronome beat recorded on the left channel, and the speaker's voice on the right channel. The recording equipment used was the Roland Edirol R-05 digital recorder, with an external microphone (Audio-Technica ATM63HE).

A total of six CVCV utterances were recorded, containing all combinations of the voiceless stops [p], [t], [k]. For each utterance, three repetitions of the trial were recorded, following the metronome. The patterns observed for three of the utterances will be discussed here: [pata], [tapa], [paki]. For the Georgian speakers these utterances were real Georgian words, while for the French speakers they were nonsense words. We are aware that this difference alone may determine different reorganization patterns in the two languages (Frank 2011). The coordination modes employed in real words may be more resistant to reorganization than in non-words.

Results

We propose that language-specific phonotactics and language-specific prosody can interact with the emergence of intrinsically stable coordination modes in rate-driven reorganization. They make contradictory predictions for the two languages, summarized in Table 1.

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TABLE 1. Predicted reorganization patterns, based on language-specific phonotactics and language-specific prosody.

Language	CVCV > CCV more likely	CVCV > CCV less likely
Georgian	Unconstrained complex onsets	Initial prominence
French	Final prominence	Moderately complex onsets

1. Based on language-specific phonotactic differences, we predict that, under rate increase, overall gestural reorganization from CVCV to CCV is most likely to occur in Georgian, where complex onsets are commonly allowed. French has stronger restrictions on complex onsets, and this type of reorganization is therefore less likely to occur.

2. Based on language-specific prosodic differences, we predict that, under rate increase, disyllables with initial prominence (Georgian) will be more resistant to reorganization to CCV than disyllables with final prominence (French).

If reorganization were driven solely by bio-mechanical constraints on articulation, we would expect similar patterns of gestural reorganization in all utterances, in both languages. Recent studies using an acceleration paradigm have shown that initial prominence can block the shift from two to one jaw cycles per syllable (Lancia & Fuchs 2011 for German; Carrissimo-Bertola et al. 2012 for Italian). By choosing two languages that also differ in phonotactics, the present study can provide information on the relative importance of the two linguistic patterns in determining articulatory routines.

Given individual differences in speech rate, we present and compare here data from individual speakers.

Front-to-Back (pata) vs. Back-to-Front (tapa) in Georgian

The Georgian word [p^{h}at^{h}a] 'stalemate' was repeated three times by each speaker following the metronome beat. Georgian has two series of voiceless stops: voiceless aspirated and voiceless ejective. All speakers systematically showed loss of aspiration and of glottalization very early on during each trial.

The use of the sigmoid-shaped increase in rate revealed two types of reorganization: one during the acceleration phase before reaching the final plateau, and one during the final plateau. We observed first a shift from initial to final prominence (pAta > patA), followed by a shift to [pta]. Figure 1 shows a representative example of both types of reorganization from the same Georgian speaker (pAta > patA > ptA).

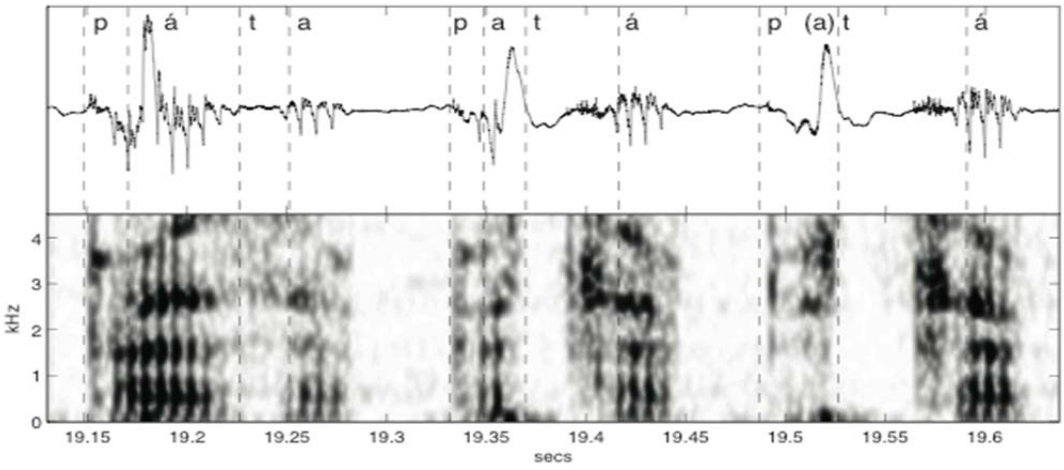


FIGURE 1. Georgian. Example shift from initial to final prominence in [p^{h}at^{h}a] (V2 duration increases relative to V1), followed by elision of V1 (*pata → pta*). Speakers typically persist in the CCV pattern following reorganization.

Data from nine of the fifteen Georgian speakers was analyzed. All nine speakers shift from initial to final prominence *(pAta → patA),* and seven of them shift all the way to *pta* (Figure 2). V1 elision is licensed by Georgian phonotactics.

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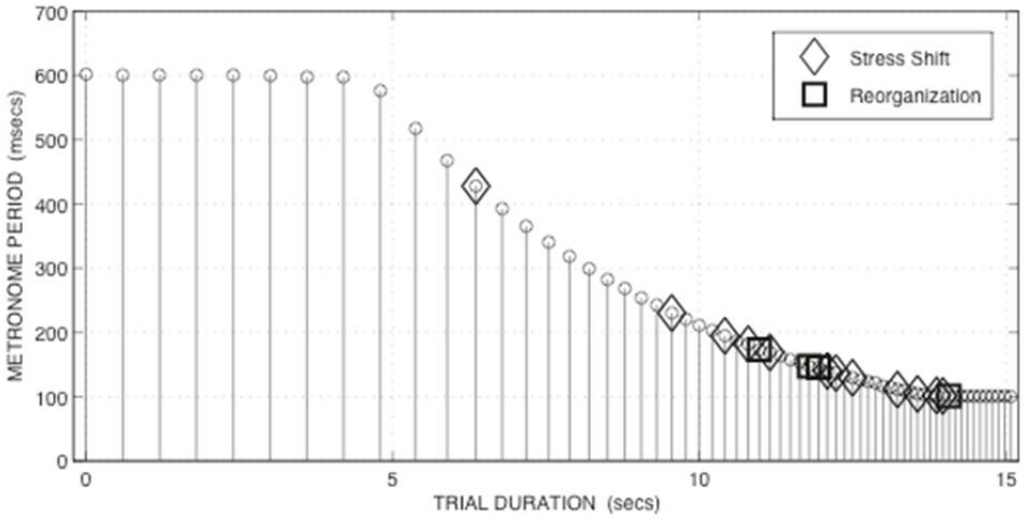


FIGURE 2. CCV reorganization: results for p^hat^ha pooled across all trials and speakers (some transition points contain multiple events). All nine speakers shifted stress *(páta → patá).* Seven speakers also showed initial vowel elision *(patá → ptá).*

Comparatively less reorganization is observed in t^hap^ha 'small hill', as predicted. There is no reorganization to CCV. All nine speakers reduce the final vowel *(tapa → tap)*. Stress shift from initial to final prominence *(tApa → tapA)* occurs for only one speaker, in two out of three repetitions, but is not followed by V1 elision. The absence of V1 elision in *tapa* is not predicted by biomechanical constraints, but is consistent with the Georgian place order asymmetry, where back-to-front *(t-p)* sequences are less tightly coordinated than front-to-back ones *(p-t).*

Front-to-Back (pata) vs. Back-to-Front (tapa) in French

We examined data from two of the six French speakers. For one of the speakers the only change observed was a shift from final to initial prominence in all three trials of both utterances: *patA → pAta* and *tapA → tApa*. For the second speaker the prominence shift occurred only for [tapa], with reduction of the final unstressed vowel: *tapA → tApa → tAp*. No change was observed for [pata]. Note that the absence of real words did not encourage reorganization, relative to the Georgian experiment, where real words were used.

The overall absence of V1 elision is actually consistent with French phonotactics, even though Rochet-Capellan & Schwartz (2007) report V1 elision for both utterances: *pata → pta* and *tapa → pata → pta*. At this point the different results for French require further investigation, but they may be due to the different experimental setups employed.

[paki] in Georgian

An utterance with non-identical vowels – [p'ak'i] – tests the prediction that reorganization from two jaw cycles per utterance (2:1 frequency) to one jaw cycle (1:1 frequency) can also be achieved by vowel coalescence. Two Georgian speakers showed coalescence of the two vowels into a CVVC pattern *(paik)* during the acceleration phase (Figure 3). As rate increases, we observe that the phasing of /k/ changes, revealing more of the /a:i/ transition. There is no evidence of vowel reduction, but the tongue dorsum constriction is applied later, supporting evidence for reorganization.

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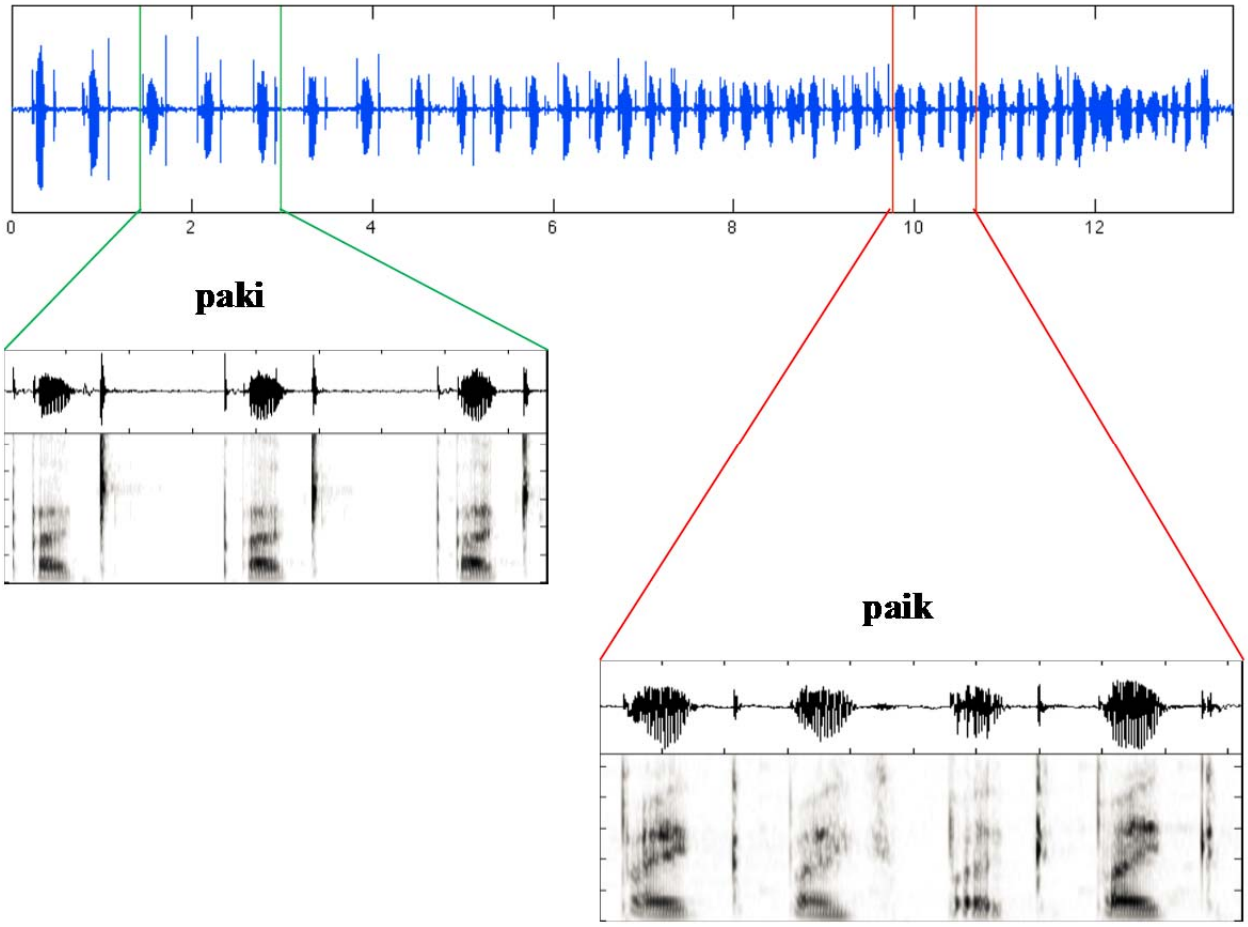


FIGURE 3. Georgian *paki* → *paik*. Re-phasing of /k/, as rate increases.

It can be argued that the *paki* → *paik* change can simply be due to increased V-to-V coarticulation, and to the reduction of the final unstressed vowel, both expected under rate increase. If this were the case, the coarticulated vocalic portion between the two stops would also be expected to shorten in duration. But if the change is due to gestural reorganization rather than reduction, then the coarticulated vocalic portion is not expected to shorten with increasing rate. On the contrary, as [paki] turns to [paik], the vocalic portion between the two stops should represent a higher percentage of the duration of the inter-burst interval, between the onset of the [p] release burst and the onset of the [k] release burst. If the [k] gesture is sliding rightward, it will be revealing more of the vowel [i]. Gestural reorganization thus predicts that the duration of the vocalic portion will gradually increase with speech rate, and that the ratio of the vocalic portion to the [p]-to-[k] inter-burst interval will also increase. Figure 4 shows plotted data for the three [paki] trials of one speaker. The top panels show the plotted vowel : inter-burst interval ratio. Overall, the ratio is increasing with increased rate. The bottom panel shows the plotted duration of the inter-burst interval (IBI) in blue (with the vocalic portion duration overlaid, in red). Crucially, we see that the inter-burst interval is shortening with increased rate.

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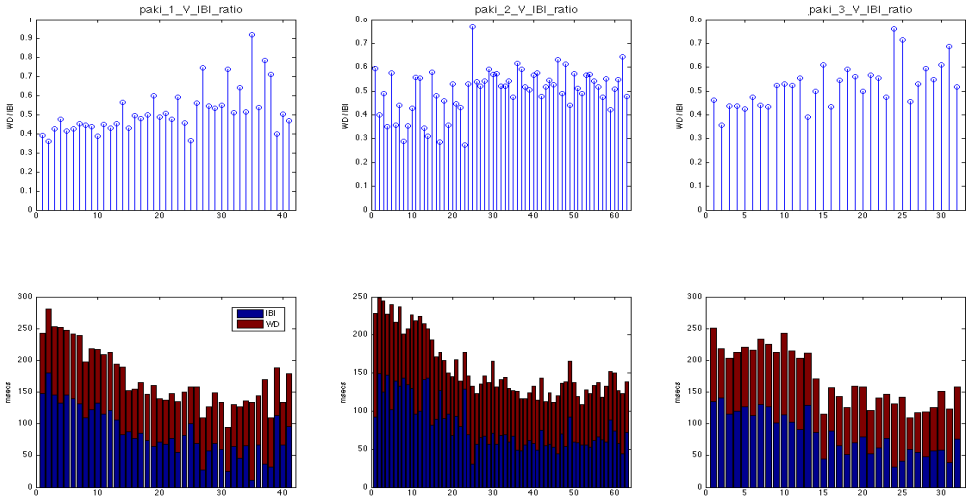


FIGURE 4. Georgian *paki* → *paik*. Top panels: ratio vocalic portion to inter-burst interval (IBI). Bottom panels: vocalic portion duration in red (ms) overlaid on IBI duration in blue (ms).

This result confirms that the acceleration paradigm leads to a reorganization of the existing gestures, rather than to their reduction.

Conclusions

The data we have presented support the hypothesis that reorganization triggered by manipulating a control parameter (speech rate) is not subject solely to biomechanical constraints, but shows effects of language-dependent timing patterns. In Georgian, the accelerated repetition of the utterance [p^hat^ha] results in a front-to-back complex onset [pta], whereas the accelerated repetition of [t^hap^ha] does not. This result is consistent with the order of place asymmetry observed in Georgian (Chitoran et al. 2002), which predicts different reorganization patterns depending on the order of place. It is not consistent with the Labial-Coronal effect (Locke 1983, MacNeilage & Davis 2000, Rochet-Capellan & Schwartz 2007), which predicts reorganization to [pta] for both utterances. In French, the absence of CVCV-to-CCV reorganization is also consistent with French phonotactics.

The [paki] to [paik] reorganization is also consistent with Georgian phonotactics. Even though [pk] is a legitimate complex onset in Georgian, it is possible that 1:1 frequency through vowel coalescence (CVVC) is favored over CCV, when the particular vowel combination is allowed. This is a question for further research, and for comparison with the French [paki] utterance.

Studying articulatory reorganization is important, as it provides a window into speech planning by observing rate-driven optimization of gestural synergy (e.g., simplification of jaw cycle), and reorganization of frequency ratios within syllables. The preliminary experiments we report here confirm that studying it from a cross-language perspective is essential, if we want to fully understand the balance between the bio-mechanical and cognitive forces shaping human speech.

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