Locality interactions with prominence in determining the scope of phrasal lengthening

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Temporal lengthening of gestures and segments located in a boundary-adjacent syllable has been found in both pre- and postboundary contexts. However, the temporal extent or scope of this lengthening, particularly in the articulatory domain, is not well described. We address the question of scope of prosodic lengthening by considering specifically whether prominence interacts with boundary-related articulatory lengthening in such a way that prominent elements not immediately at a phrase edge are lengthened relative to the same prominent elements phrase-medially (i.e. at a considerable distance from a boundary). Articulatory kinematic data were collected for three subjects to analyze consonant constrictions of prominent syllables located (1) either immediately before or after a boundary and (2) two and three syllables away from that boundary. The results indicate that, as expected, gestures undergo prosodic lengthening when immediately local to the phase boundary. However, some subjects did display prosodic lengthening at a small remove from the boundary for a prominent syllable. This effect was strongest in the postboundary condition. These results suggest that a consideration of prominence may be relevant in understanding the temporal patterning of boundary-related articulatory lengthening.

1 Introduction

1.1 On the scope of phrasal lengthening

Research in phonetics has shown that linguistic prosodic structure affects both articulatory and acoustic quality of segments. For example, acoustic segment length is found to be longer both immediately before and after prosodic boundaries (e.g. Oller 1973, Klatt, 1976, Wightman et al. 1992). This generalization additionally holds true in the articulatory domain; many studies have shown that segments near a prosodic boundary (and on both sides of the boundary) have articulatory durations longer than like segments far from a prosodic boundary (Krivokapić 2007b; phrase-finally: Byrd & Saltzman 1998, Byrd 2000, Tabain 2003, Cho 2004; phrase-initially: Byrd & Saltzman 1998, Cho & Keating 2001, Fougeron 2001, Cho 2004). Articulatory lengthening has also been demonstrated to be proportionate to the strength of the boundary; the stronger the prosodic boundary, the more articulatory lengthening has been

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observed (e.g. Fougeron & Keating 1997, Byrd & Saltzman 1998, Keating et al. 2004, Cho 2006, Krivokapić 2007b, Byrd & Choi to appear).

The temporal scope of prosodic boundary effects refers to how far removed from the boundary the effects are observed. The temporal scope of boundary effects is relatively unexamined, particularly in articulation. However, there are acoustic studies that have considered this research question. The data from a series of experiments presented in Oller (1973) suggest that non-boundary-final stressed syllables undergo prosodic lengthening when near a prosodic boundary. Work on prosodic lengthening in Hebrew by Berkovits (1993a) suggests a 'far greater proportion of lengthening in the final stressed syllable . . . compared to the initial unstressed syllable' (p. 95). Berkovits (1993b) additionally finds a greater magnitude of prosodic lengthening in stressed environments versus unstressed environments. In another study on the effect of prosodic lengthening on acoustics, in this case in Hebrew, Berkovits (1994) finds lengthening in the initial stressed syllable of a boundary-adjacent bisyllabic word, but no lengthening is found for an initial unstressed syllable in a boundary-adjacent bisyllabic word. The study additionally found that lengthening was greater in magnitude for each consonant approaching the boundary. Dutch too has been shown to have preboundary lengthening in stressed syllables not immediately adjacent to the boundary when the syllable immediately adjacent to the boundary contained a reduced vowel (Cambier-Langeveld, 1997), although both the Berkovits and Cambier-Langeveld studies may not extend necessarily to English.

Work on English by Shattuck-Hufnagel & Turk (1998) shows that stress can attract lengthening. This study found that while the majority of boundary-related lengthening happened in the syllable immediately adjacent to the boundary, a non-edge-adjacent stressed syllable also underwent boundary-related lengthening, as the lengthening phenomenon extended 'leftward to include the most prominent syllable in the word' (p. 1236). Similarly, Turk (1999) clearly attributes certain boundary-related lengthening data to the presence of lexical stress. In this study, it was found that phrase-final lengthening was not limited to the boundary-adjacent syllable and can spread leftward if lexical stress is present. Most importantly, it was found that in unstressed boundary-adjacent syllables, no significant lengthening happened; the prosodic lengthening occurred in a stressed syllable removed from the boundary. Finally, Turk & Shattuck-Hufnagel (2007) present results that reinforce the possibility that stressed syllables removed from the boundary show phrase-final lengthening. This study measuring the acoustic duration of syllables found that phrase-final lengthening occurred most often for boundary-adjacent syllables but that statistically significant lengthening also occurred for the rime of main-stress syllables when these syllables were not adjacent to the boundary. The authors assert that the distribution of 'boundary-related lengthening . . . cannot be explained without reference to the location of main lexical stress' (Turk & Shattuck-Hufnagel 2007: 445).

The studies reviewed above focus on the co-occurrence of lexical stress and lengthening in the acoustic domain when a prominent syllable is non-final in the phrase. The interaction of boundary-related lengthening and prominent syllables at an initial phrase edge has not been examined and, to date, few studies in the articulatory domain address the scope of boundary-related lengthening.

Byrd & Saltzman (1998) find articulatory lengthening in constriction formation duration of an onset consonant in a CV before a prosodic boundary; however more lengthening is found in an onset consonant of a CV immediately following the boundary. Examining linguapalatal contact, Fougeron & Keating (1997) find prosodic lengthening to extend beyond the boundary-initial segment to include other segments in the boundary-initial syllable. Byrd, Krivokapić & Lee (2006) examine articulation across a greater number of syllables and find little articulatory lengthening at a distance. Finally, Krivokapić (2007) finds articulatory lengthening up to two consonant constrictions preboundary and one or two consonants postboundary, with effects waning in magnitude as remoteness from the boundary increases.

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However, we are aware of no studies that look explicitly at the interaction of phrasal juncture and prominence in the articulatory domain in syllables not at a phrase edge. Thus, the interaction between prominence and the scope of boundary-related lengthening in articulation remains unclear. It is wise to realize, however, that the interaction of prosody and stress is likely to be language-specific, as Cho & McQueen's (2005) acoustic study on phrase-initial effects suggests. The above studies in acoustics and articulation do indicate that the scope of prosodic juncture lengthening is not limited to boundary-adjacent segments and may sometimes extend to gestures remote from the boundary. Below, we present a study specifically manipulating prominence of syllables in the neighborhood of a prosodic boundary in order to better understand the temporal scope of phrasal lengthening. All of the stimuli in the current study contained lexical stress in the target syllable. While pitch accent was not overtly controlled in order to allow for the most natural reading possible, it was the case that all subjects produced pitch accents at this point in the majority of utterances (see section 2 below).

1.2 The π-gesture framework for prosodic influences in speech production

A series of experiments and computational simulation work has led to the development of a computational model of junctural lengthening called the π-gesture (prosodic-gesture) model (Byrd et al. 2000, Byrd & Saltzman 2003, Byrd et al. 2006). This framework extends a fundamental insight of Articulatory Phonology's conception of phonological units (e.g. Browman & Goldstein 1992) to the prosodic level – namely, the view that linguistic cognitive units of phonological representation are dynamic and temporal in nature, rather than atemporal and symbolic. Within the π-gesture framework, prosodic boundaries are viewed as having a temporal extent or interval of activation. During this interval of activation, a π-gesture acts to slow the pacing of any coproduced constriction activation trajectories. This interval of local slowing or warping of speech rate, which has been shown in computational modeling to yield lengthened articulator trajectories and lessened overlap (Byrd & Saltzman 2003), must, like all gestures, be coordinated with other phonological material.

When the term SCOPE of prosodic lengthening is used in the context of the π-gesture model, it refers to the constriction events in the gestural score that co-occur with the activity of a π-gesture, so consequently, the phonological interval over which the local prosodic slowing can be observed. For the purposes of experimental design and exposition, syllable (or segment) count is often used to quantify scope and we do likewise here. However, we wish to clarify that we do not grant this 'counting' any theoretical status. Rather, we assume that scope of boundary effects is defined in terms of the activation intervals and coordination of phonological units in an abstract planning domain (see e.g. Goldstein, Byrd & Saltzman 2006). The scope of a π-gesture will be determined by two (potentially interacting) characteristics: first, the particular temporal extent of the π-gesture itself; and second, the coordination or alignment of the π-gesture with the constriction events in the neighborhood of the boundary. As has been reviewed above, the experimental data to date suggest that the scope of the π-gesture or prosodic lengthening is not large and is relatively local to the boundary. It remains to be seen, however, whether qualitative properties of the phonological units near the phrase edge (such as prominence) can under certain circumstances influence the scope of articulatory phrasal lengthening.

1.3 Experimental investigation

Given previous research, it is expected that segments immediately adjacent to the boundary will exhibit longer durations than segments remote from a boundary. Byrd et al. (2006) did not find consistent temporal lengthening in gestures in unstressed positions remote from the boundary. However, it is uncertain whether gestures located in syllables that are somewhat removed from the phrase edge but which are prominent may be affected by prosodic lengthening. That is, it is unknown whether (and under what conditions) constrictions that

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occur in segments near, but not strictly local to the boundary, will exhibit longer durations than similar ones phrase-medially.

Below we present a kinematic articulatory study on consonant production conducted using magnetometry. This experiment investigates whether or not boundary-related lengthening is strictly local, i.e. edge-adjacent, or may be attracted toward syllables somewhat remote from the boundary. In particular, boundary-related lengthening may be sensitive to the presence of PROMINENT syllables that are not immediately at the phrase edge. We manipulate this prominence by placing lexically stressed syllables at varying distances from the phrase edge. These syllables are both rhythmically strong and are also a potential locale for pitch accent. Overall they can be expected to allow us to observe the effects of prominence on boundary-related articulatory lengthening.

Empirically, this is of interest for understanding possible patterns of articulatory lengthening at phrase boundaries. Additionally, it is of further theoretical relevance for the π-gesture model of phrase boundaries. We wish to understand whether or not it is possible for the π-gesture to be temporally coordinated with tract-variable gestures not only immediately local to the boundary but also attracted to constrictions removed from the boundary in the presence of prosodic or metrical prominence. Such an attraction would potentially engender prosodic lengthening of articulatory events somewhat removed from the phrase edge.

The current study examines this research question using articulatory data from three subjects for labial and lingual constriction gestures both pre- and postvocalically and pre- and postboundary, as well as looking at their coordination in the syllable. Importantly, the speakers produced sentences with an un-instructed prosody so that the effect of prominence in general could be observed without eliciting unusual or exaggerated focus, such as emphatic focus or instructed focus placed on certain lexical items.

2 Method

Electromagnetic articulography (Carstens AG200 EMA system) was used to record the motion of sensors adhered to articulators. Transducers were adhered to the articulators of interest: the lips (at the vermillion border) and the tongue tip (approximately 5 mm from the endpoint of the protruded tongue). The sampling rate for the articulatory data was 200 Hz, and the simultaneous audio data was captured at a sampling rate of 16 kHz. Head-movement correction was applied to the data by using transducers adhered to the maxilla and bridge of the nose; for each subject, data was rotated to the sampled occlusal (or bite) plane to define the x–y coordinate system.

2.1 Subjects and stimuli

The consonants that were of interest in the current study were [m] and [d]. These consonants appeared in the syllable 'mod'. This syllable occurred in six different test conditions having an IP boundary: one syllable away from the boundary (i.e. in the syllable immediately adjacent to the phrase edge), two away, and three away, both before (preboundary) and after (postboundary) an IP boundary. Recall that the position of the lexically stressed syllable with respect to the phrase edge was the independent variable of primary interest. Control sentences contained 'mod' in identical segmental contexts as the test sentences but lacked the phrase boundary occurring in the test sentences; that is, 'mod' in the control sentences was phrase-medial. To manipulate stress placement, preboundary the words 'mod#', 'modest#', and 'modestly#' were used, and postboundary, the strings '#mod,' '#a model' and '#as a model' were used. Stimulus sentences were controlled for segmental composition surrounding the target consonants. The stimuli are given in table 1. Each test sentence is paired with a control sentence having the same target word string, but differing only in the presence of a boundary.

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Table 1 Stimuli sentences (bolding was not present for the subjects).

test (boundary)/ control (no boundary)	preboundary/ postboundary	syllable distance	stimuli
test	preboundary	1	At the pageant, you're instructed that a beauty queen behaves **mod**. As each viewer watches, a winner gets crowned.
control	(preboundary)	1	At the pageant, a beauty queen behaves **mod** as each viewing occurs on stage.
test	preboundary	2	At the pageant, you're instructed that a beauty queen behaves **mod**est. Each viewer watches a winner get crowned.
control	(preboundary)	2	At the pageant, a beauty queen behaves **mod**est each viewing on stage.
test	preboundary	3	At the pageant, you're instructed that a beauty queen behaves **mod**estly. Viewers watch a winner get crowned.
control	(preboundary)	3	At the pageant, a beauty queen behaves **mod**estly viewing winners get crowned.
test	postboundary	1	At the pageant, a beauty queen is judged by what she behaves as. **Mod** and contemporary is Bambi's approach in answering.
control	(postboundary)	1	At the pageant, a beauty queen behaves as **mod** and contemporary.
test	postboundary	2	At the pageant, a beauty queen is judged by what she behaves as. A **mod**el and contemporary actress, career is Bambi's focus in answering.
test	postboundary	3	At the pageant, a beauty queen is judged by how she behaves. As a **mod**el and contemporary actress, Bambi answers with composure.
control	(postboundary)	2, 3	At the pageant, a beauty queen behaves as a **mod**el and contemporary actress.

Notice that for the postboundary condition, test sentences 2 and 3 (i.e. having the stress in the second and third syllable after the boundary) are paired with the same control sentence since the target word string was identical in both these sentences (only boundary placement differed, which was, of course, irrelevant in the control sentence having no boundary). One other point to note is that above we refer to 'mod' as a syllable, however when this string of segments occurs in the word 'model' and 'modestly,' the [d] might be considered as phonologically syllabified as an onset of the second syllable or as ambisyllabic. This status is not crucial to the experimental hypothesis as it is the canonical order of the consonants and thereby their distance from the boundary that is of interest. So while we may refer to [d] as marking the end of the test syllable 'mod', what is experimentally important is that the test sentences always matched their paired control sentences in this regard and with respect to stress placement. In summary, the experimental stimuli have segmental context tightly controlled, allowing prosodic effects to be interpreted directly as the result of boundary presence/absence and the position of a prominent syllable with respect to that boundary.

In this report, we use the term prominence as a cover term to refer to the presence of either lexical stress and the possible additional presence of a pitch accent. In order to provide a more detailed view for the reader of the pitch accent and break indices of these sentences as read by our subjects, the token that informal listening determined to be most like its other repetitions for each subject was selected for transcription by a ToBI-trained transcriber. (Note that the

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productions across repetitions were very consistent.)[1] In general, the test sentences always had a bigger boundary than the control sentences; the control sentences generally ranged from no boundary to an ip boundary, and the test sentences always had an IP boundary.

Three subjects were recorded, all were native speakers of American English without any known speech or hearing deficits. The subjects are denoted below as A, L, and S. Subjects A and L read eight randomized test blocks and eight randomized control blocks. Subject S read seven randomized test and control blocks. Randomizations differed for each subject and block. Test blocks contained six sentences, and control blocks contained five sentences. Thus, a total of 88 sentences were recorded for subjects A and L, and 77 sentences were recorded for subject S. Test and control sentences were put into separate blocks so as to minimize within-condition prosodic variability in the readings; this blocking creates a situation in which a subject's choice of prosody for a written sentence is consistent across observations.

Recall that lexical stress or rhythmic prominence in these sentences was allowed to interact naturally with pitch accent or prominence in order to examine the general effect of (uninstructed) prominence on the boundary-related lengthening. The lexically stressed syllable in both control and test sentences was eligible to receive a pitch accent. And, indeed, all speakers placed a pitch accent on this rhythmically prominent syllable in all 33 sentences with only three exceptions – preboundary in A's 3σ control and postboundary in A's and L's $2/3\sigma$ control sentences.

2.2 Data analysis

The first order derivatives (velocity trajectories) of the articulator position trajectories were used to identify important kinematic landmarks in the consonant ([m] and [d]) constriction formation. These trajectories were smoothed with a 15-Hz low-pass filter. Different signals were used for the two test consonants. For the [m], Lip Aperture – the Euclidian distance between transducers on the upper lip and lower lip – was calculated as the relevant trajectory. Velocity zero crossings and extrema were algorithmically identified, using MView (under development, M. Tiede) in Matlab. For the [d], the horizontal (x) and vertical (y) transducer movement was used to calculate tangential velocity (which incorporates movement in both dimensions; as detailed in Löfqvist, Gracco & Nye 1993), for which minima and maxima were identified; tangential velocity minima being the critical indicator of gesture edges.

Two kinematic landmarks of both gestures were of importance for the current study. The first was the constriction formation onset. Constriction formation onset was defined in the bilabial gesture as the first velocity zero-crossing in the Lip Aperture trajectory. A criterial threshold of 2% of the range between the local velocity maximum and minimum local velocity was used to define the departure from zero-velocity for all measures used here. For the tongue tip gesture, constriction formation onset was defined by the timepoint of tangential velocity minimum (the same 2% threshold setting was used for tangential velocity minima). The

[1] ToBI transcription details are as follows:
SUBJECT A Controls: No boundary except preboundary 2s which had an ip.
A L* or H* pitch accent occurred, excepting the 3s preboundary and postboundary 2/3s, which had no accent.
Test: All boundaries are IPs. All preboundary test words had a L* or H* accent; postboundary test words had L+H*.
SUBJECT L Controls: Preboundary had ip, except for 3s; postboundary controls had no boundary.
Preboundary had L*, except for 3s which had a H*; postboundary had no accent.
Test: All boundaries are IPs. All preboundary test words had H* accent; postboundary test words had L+H*.
SUBJECT S Controls: Preboundary 1s had ip; 2s and 3s had a small IP. 1s and 2s had L*; 3s had L*+H. Postboundary had ip.
Tests: Pre- and postboundary had IPs subjectively definitely larger than control.
Pitch accents preboundary had L* or H*; postboundary 1s and 3s had L*+H; 2s had H*.

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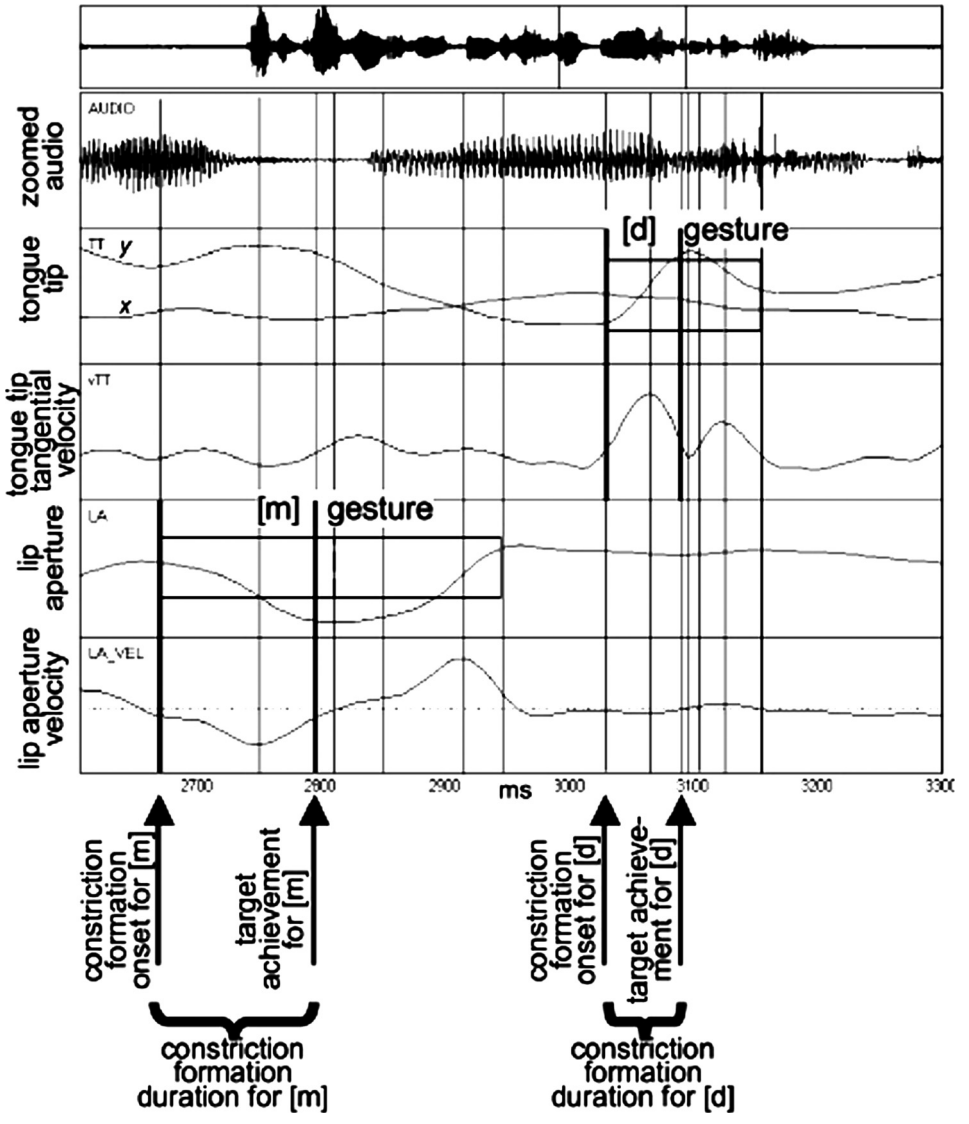


Figure 1 An example token demonstrating the data marking procedure ('. . . as mod a[nd] . . .'). Note that while thresholded velocity events were used to determine these timepoints, the markings are shown in both the velocity and position panels.

second kinematic landmark that was of importance was the timepoint of target achievement for the constriction, which was defined as the second thresholded velocity zero-crossing (for Lip Aperture) or tangential velocity minimum (for Tongue Tip*xy*). An example of the kinematic marking procedure is shown in figure 1.[2]

The labial information for subject L had to be excluded for certain conditions for the reason that too few tokens were acceptable for data analysis. This is because the speaker

[2] Note that due to the standard thresholding, the marked timepoints fall slightly internal to the visual inflections in the position signal; this is intended to ensure that small fluctuations around velocity zeros/minima do not yield spurious results and that active movement onsets are correctly captured.

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either had a large amount of co-articulation between the labial gestures in [v] and [m] in the sentences resulting in a single continuous movement, or multiple peak velocities during that movement, not allowing an independent onset/target for the [m] to be observed.[3]

From these two timepoints for constriction formation, two dependent variables were calculated:

- Constriction Formation Duration: The time (ms) from constriction formation onset to constriction target achievement;
- Delta Peaks: The time (ms) from [m] constriction target achievement to [d] constriction target achievement.

Since it reflects the coordination of the 'mod' sequence's initial and final consonant constrictions, the delta peaks variable also serves as an indirect indicator of syllable duration.

Unpaired, one-tailed t-tests were conducted to compare means of test versus control conditions, separately for each subject, with a criterial p-value set at $p < .05$. The one-tail was chosen because previous research on articulation and prosody suggests that significant articulatory lengthening and overlap decrease are expected for the boundary (test) condition as compared to the non-boundary (control) condition.

3 Results

3.1 Preboundary constriction formation duration

A comparison of means in the boundary condition versus the non-boundary condition was conducted for the constriction formation duration for [m] in the string 'mod' before the intonational phrase boundary. (Recall that subject L's [m]'s could not be analyzed here.) Before the boundary, there was no significant lengthening for any subject in any position (one, two, or three syllables away from the boundary) for the [m] in 'mod', 'modest' or 'modestly'.

In contrast, and as predicted from early findings on prosodically driven articulatory lengthening, the [d] consonant in the syllable 'mod' that occurs immediately at the phrase edge showed significant lengthening of the constriction formation for all three subjects as compared to the non-boundary (control) condition (A: $t(14) = -1.871$, $p = .0412$; L: $t(12) = -3.758$, $p = .0014$; S: $t(10) = -1.882$, $p = .0446$).[4] When the test syllable occurred at a distance of two syllables away from the boundary, i.e. 'modest#', one subject, A, had constriction formation lengthening relative to the non-boundary control ($t(13) = -1.822$, $p = .0458$). When [d] was at the end of the third syllable away from the boundary, the constriction formation of this tongue tip gesture did not show lengthening for any subjects. Thus in summary, the preboundary prosodic lengthening effect was tightly linked to the edgemost articulation and did not tend to 'travel' further preboundary as a function of prominence placement, though one subject did show an influence at the two-syllable distance.

[3] The conditions that had to be excluded due to the co-articulation between [v] and [m] were the preboundary conditions two and three syllables away from the boundary. Additionally, the postboundary condition at a distance of three syllables had to be excluded due to issues with the kinematic landmarking software. Speaker L often had multiple peak velocities in the constriction formation of this [m] gesture, which led to an improper marking of this gesture.

[4] One might wonder if the realization of [d] in 'mod' might flap at a word boundary but not preceding a major phase boundary. This, rather than a confound, is precisely one of the durational effects of a phrase boundary that is under examination here. Further, work by Byrd & Fukaya (2005) and others have shown that flaps are not categorically distinct in the articulatory domain; Byrd & Fukaya (2005: 45) show that 'a discrepancy exists between acoustic and articulatory durational patterning – while acoustic durations of flaps are shorter than those of non-flaps overall, their articulatory durations are not uniformly so. It is important to consider multiple potential articulatory sources – both spatial and temporal – for the acoustic shortness that characterizes flaps, including spatial reduction, temporal articulatory shortening, and changes in intergestural coordination'.

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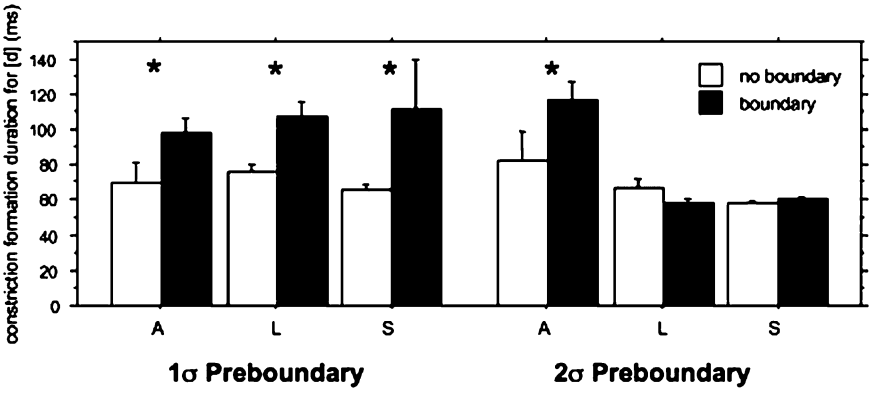


Figure 2 [d] constriction formation duration in the 1 syllable and 2 syllable preboundary condition.

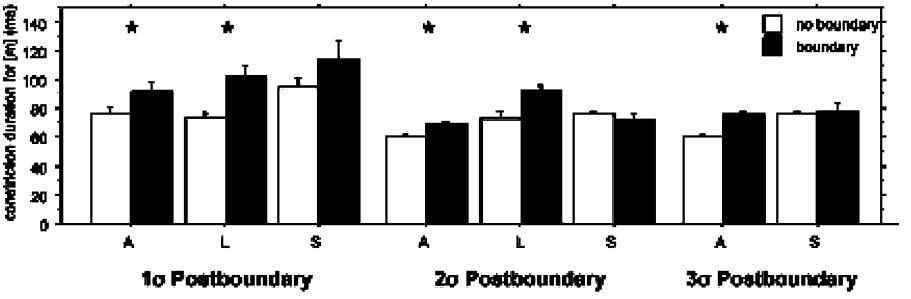


Figure 3 [m] constriction formation duration in the 1, 2, and 3 syllable postboundary condition.

The pattern of means for preboundary [d] constriction formation duration is shown in figure 2, and cell-by-cell information for the preboundary condition is given in table 2.

3.2 Postboundary constriction formation duration

When the 'mod' syllable occurred after the boundary, the [m] was then the consonant constriction closest to the phrase edge. In this postboundary case, two of the three subjects showed lengthening of [m] constriction formation duration in the position 1 (boundary-adjacent) comparison (A: $t(12) = -1.889$, $p = .0417$; L $t(14) = -3.872$, $p = .008$). When [m] occurred in a stressed syllable located two syllables away from the boundary, i.e. with an intervening stressless syllable '#a mod. . .', the same two subjects also showed lengthening in the constriction formation duration of the bilabial constriction (A: $t(13) = -3.256$, $p = .0031$; L: $t(12) = -3.501$, $p = .0022$). Finally, when the test syllable occurred three syllables after the phrase edge, i.e. '#as a mod. . .', subject A showed lengthening of the constriction formation of [m] in the boundary condition as compared to the control non-boundary condition ($t(13) = -5.673$, $p < .0001$). (Too few tokens were available for use in the 3 syllable condition for subject L's [m]s for a t-test to be considered.) The constriction formation results for postboundary [m] are shown in figure 3.

When considering the more remote [d] constriction in the postboundary condition, only one of the t-tests for one subject and one condition was significant. Only subject L had lengthening, and this lengthening only occurred in the constriction formation for [d] located in the syllable immediately adjacent to the boundary ($t(12) = -5.846$, $p < .0001$). The other subjects showed no postboundary lengthening of the [d] constriction formation. Cell-by-cell information for the postboundary condition is given in table 3.

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Table 2 Cell by cell means and t-test results for the preboundary condition (n.s. indicates not significant; NA indicates an insufficient number of tokens for analysis; n = test n + control n).

	Preboundary		
subject	constriction formation [m]	constriction formation [d]	delta peaks
	Distance = 1σ		
Subject A	n.s. Control: 66.9 (5.9) Test: 68.1 (14.1) n = 16	t = −1.871, p = .0412 Control: 70 (32.5) Test: 97.5 (25.9) n = 16	t = −3.9, p = .0008 Control: 265 (21.5) Test: 317.5 (31.4) n = 16
Subject L	NA	t = −3.786, p = .0014 Control: 75.6 (13.2) Test: 107.5 (18.6) n = 14	NA
Subject S	n.s. Control: 71.4 (14.4) Test: 60.8 (5.8) n = 13	t = −.1.882, p = .0446 Control: 65.7 (7.9) Test: 111 (64.3) n = 12	t = −2.556, p = .0143 Control: 308.6 (19.7) Test: 344 (28.5) n = 12
	Distance = 2σ		
Subject A	n.s. Control: 65 (8.7) Test: 73.6 (38.5) n = 14	t = −.1269, p = .0458 Control: 82.1 (44.2) Test: 116.9 (29) n = 15	n.s. Control: 177.1 (18.2) Test: 162.1 (18) n = 14
Subject L	NA	n.s. Control: 67.1 (13.8) Test: 58 (4.5) n = 12	NA
Subject S	n.s. Control: 69.1 (9.7) Test: 68.6 (12.5) n = 13	n.s. Control: 58.3 (2.6) Test: 60 (2.9) n = 12	n.s. Control: 202.5 (5.2) Test: 218.6 (44.8) n = 12
	Distance = 3σ		
Subject A	n.s. Control: 65.8 (13.2) Test: 61.3 (4.4) n = 14	n.s. Control: 103.6 (30.6) Test: 93.6 (38.8) n = 14	n.s. Control: 140 (12.2) Test: 144.3 (7.9) n = 13
Subject L	NA	n.s. Control: 61.9 (19.4) Test: 65.7 (2.2) n = 15	NA
Subject S	n.s. Control: 67.1 (4.9) Test: 66 (8.2) n = 12	n.s. Control: 57.9 (3.9) Test: 56 (2.2) n = 12	n.s. Control: 189.3 (12.7) Test: 167 (10.4) n = 12

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Table 3 Cell by cell means and t-test results for the postboundary condition (n.s. indicates not significant; NA indicates an insufficient number of tokens for analysis; n = test n + control n).

	Postboundary		
subject	constriction formation [m]	constriction formation [d]	delta peaks
	Distance = 1σ		
Subject A	t = −1.889, p = .0417 Control: 75.7 (14.6) Test: 91.4 (16.5) n = 14	n.s. Control: 72.9 (14.1) Test: 86.4 (25.9) n = 14	t = −.1942, p = .0422 Control: 219.3 (47.4) Test: 262.5 (31.7) n = 14
Subject L	t = −3.872, p = .0008 Control: 73.8 (10.3) Test: 102.5 (13.3) n = 16	t = −5.846, p < .0001 Control: 64.4 (9.8) Test: 96.7 (10.8) n = 14	t = −1.896, p = .0236 Control: 291.3 (41.1) Test: 340.8 (42.1) n = 14
Subject S	n.s. (p = .098) Control: 94.3 (17.7) Test: 114.3 (34.3) n = 14	n.s. Control: 61.4 (6.9) Test: 62.9 (6.4) n = 14	n.s. Control: 263.6 (33.1) Test: 268.6 (31.5) n = 14
	Distance = 2σ		
Subject A	t = −3.256, p = .0031 Control: 60.6 (5) Test: 69.3 (5.3) n = 15	n.s. Control: 66.9 (7.5) Test: 70 (6.3) n = 14	n.s. Control: 217.5 (10.4) Test: 205 (17) n = 14
Subject L	t = −3.501, p = .0022 Control: 73.3 (11.7) Test: 92.5 (8.9) n = 14	n.s. Control: 77 (25.9) Test: 75.6 (24) n = 13	n.s. Control: 287 (23.6) Test: 246.9 (31.6) n = 13
Subject S	n.s. Control: 75.7 (6.1) Test: 72.1 (9.1) n = 14	n.s. Control: 57.1 (3.9) Test: 60, (9.6) n = 14	n.s. Control: 224.3 (14) Test: 215.7 (17.9) n = 14
	Distance = 3σ		
Subject A	t = −5.673, p < .0001 Control: 60.6 (5) Test: 75.7 (5.3) n = 15	n.s. Control: 66.9 (7.5) Test: 65.7 (11.3) n = 15	n.s. Control: 217.5 (10.4) Test: 190 (19.8) n = 15
Subject L	NA	n.s. Control: 77 (25.9) Test: 67.5 (26) n = 13	NA
Subject S	n.s. Control: 75.7 (6.1) Test: 78.3 (12.9) n = 13	n.s. Control: 57.1 (3.9) Test: 54.2 (4.9) n = 13	n.s. Control: 224.3 (14) Test: 204.2 (25.2) n = 13

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3.3 Summary of constriction formation duration results

The postboundary results for 'mod' mirror the pattern of preboundary results for 'mod' in that the consonant closest to the boundary (i.e. the [d] on the preboundary side and the [m] on the postboundary side) show boundary-related lengthening when at the phrase edge. Consonants in prominent syllables further away from the boundary are less likely to exhibit prosodic lengthening, although, this may occur asymmetrically for consonants in a postboundary prominent syllable.

When such a prominent syllable occurs after but relatively close to a boundary, it may exhibit prosodically-driven articulatory lengthening. Note that 'a' and 'as a' in the postboundary condition are extremely short intervening unstressed syllables. For one subject (subject A), boundary-related lengthening of the onset of the prominent syllable occurred as many as three syllables after from the phrase edge, and another subject (L) showed this pattern two syllables away. In the preboundary case however, there was much more modest evidence of a prominence effect. While all subjects showed lengthening of an immediately preboundary [d], only one showed such lengthening when this consonant occurred at a position one syllable removed from the phrase edge. It is possible that this pre-/postboundary difference may be because in the preboundary condition the intervening syllables ('est' and 'estly') are longer (simply by virtue of containing more phonological material).

3.4 Delta peaks

The third dependent variable examined in the current study was the temporal interval between the achievement of the constriction target in [m] to the achievement of the constriction target in [d]. This, we mentioned, is an indirect measure of articulatory syllable duration because it reflects the coordination between the two consonants in the 'mod' string (and likely is influenced by their coordination(s) with the vowel, as well).

The results indicate that this variable is only affected by the boundary context when the target string occurs immediately adjacent to the boundary. Significant results occur for this syllable condition in both the preboundary context and the postboundary context. For the preboundary condition, only subjects A and S could be included. At position 1, both speakers showed boundary-related lengthening of delta peaks (A: $t(14) = -3.900$, $p = .0008$; S: $t(10) = -2.556$, $p = .0143$). In the postboundary condition at position 1, subjects A and L had a longer time between the targets for [m] and [d] than when no boundary occurred (A: $t(11) = -1.896$, $p = .0422$; L: $t(12) = -2.210$, $p = .0236$). No subjects showed lengthening for this variable in the conditions further away from the boundary, on either side of the boundary. Cell-by-cell information is given in tables 2 and 3. In summary, the delta peaks variable for the 'mod' string only showed an influence of phrasal structure when this string was at a phrase edge.

4 Discussion

In summary, boundary-related articulatory lengthening of consonants adjacent to the boundary and of the articulatory interval spanning the consonants (delta peaks) for a boundary-adjacent syllable was prevalent, as has been found in other articulatory studies. Further, the current study was intended to investigate the question of whether prosodic lengthening occurs in prominent syllables at a distance removed from the boundary. To a degree, the answer to this question is subject dependent. Subject S never showed lengthening beyond the syllable immediately at the phrase final or initial edge; however, consonant constriction lengthening for the other two speakers did show some sensitivity to stress at a small remove from the boundary. Before the boundary, this lengthening was observed for one subject for the final constriction in the lexically stressed test syllable preceding the phrase-edge syllable, and after

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a boundary it was observed for two subjects for the initial constriction formation in the test syllable following the phrase-edge syllable.

The lack of wide scope effects for Speaker S merits a further comment. This subject's preboundary 2σ and 3σ control sentences had an intonationally marked break that the other subjects did not. Of course, the boundary at S's paired test sentences was clearly much larger; however the presence of a noticeable break in the control sentence likely minimized test versus control differences in these two cells.

Results from subjects A and L above suggest that syllable stress and its prosodic consequences can in a limited way attract lengthening in positions removed from the local phrase edge. In another articulatory study of prosodic scope, Byrd et al. (2006) investigated boundary-related lengthening in positions removed from the boundary. It was found that prosodic lengthening other than immediately local to the boundary was scarce (and in some cases, postboundary articulatory shortening occurred after edge-adjacent lengthening.) However, the present study differs from Byrd et al. (2006) in that the target sequence was prominent by virtue of bearing lexical stress and generally pitch accent and having short unstressed syllables intervening between the prominent target syllable and the phrase edge. The asymmetry observed here between the pre- and postboundary conditions is interesting in that Krivokapić (2007a, b) has suggested that pausing phenomena at phrasal junctures is sensitive to upcoming phonological and prosodic structure for the purpose of speech planning. The present study might also be taken as a hint that planning influences the properties of a junctural prosodic (π-)gesture.

If further studies confirm the weak findings here that junctural lengthening is or can be sensitive to other prosodic events in the vicinity of the boundary, two possible interpretations of this sensitivity within the π-gesture model (Byrd & Saltzman 2003) of phrasal lengthening arise as possibilities. The first possible interpretation is that prosodic patterning of the nearby phonological constriction events influences the relative temporal organization of the activation interval of the π-gesture with respect to those constriction events. A π-gesture (of some particular fixed activation interval) could shift in a limited way in its coordination, effectively attracted in the direction of a locally stressed or pitch-accented syllable. This possibility is shown in the top panel of figure 4 for a situation having a postboundary prominent syllable, with the designation 'coordination shift' account.

The second possibility concerns not the coordination of the π-gesture but rather its temporal extent relative to the constriction gestures. The π-gesture edge, i.e. its beginning or end of activation, could be attracted toward – 'reach out' toward – an alignment with a local primary-stressed or pitch accented syllable. An example of this is shown in the second panel in figure 4 for a situation having a postboundary prominent syllable, with the designation 'extension' account. Under this scenario, the phrasal lengthening simply lasts or persists longer in time.

It is possible that scope effects on phrasal lengthening in articulation, whether implemented via coordination shift or extension, could be asymmetrical. There may be planning reasons why a π-gesture may be more likely to remain active longer to influence a postboundary prominent syllable than to reach backwards from a final phrase edge to start earlier. However, one subject in this study did show the effect for both pre- and postboundary syllables.

The results presented above allow us to lay out these two possibilities, but further empirical work will be necessary to differentiate them. The shift account, but not the extension account, predicts that there will be a trading relation in that the presence of a prominent syllable near a boundary and attracting the π-gesture will decrease the magnitude of the lengthening exhibited by the syllables at the opposite edge of the π-gesture. This is because, if the π-gesture for example shifts rightwards (as shown in figure 4, though the reverse arrangement is of course possible), the gestures early in the π-gesture's field of activation would become coproduced with a portion of LESSER activation of the now-shifted π-gesture. In contrast, under the extension account, constriction lengthening away from the prominent syllable

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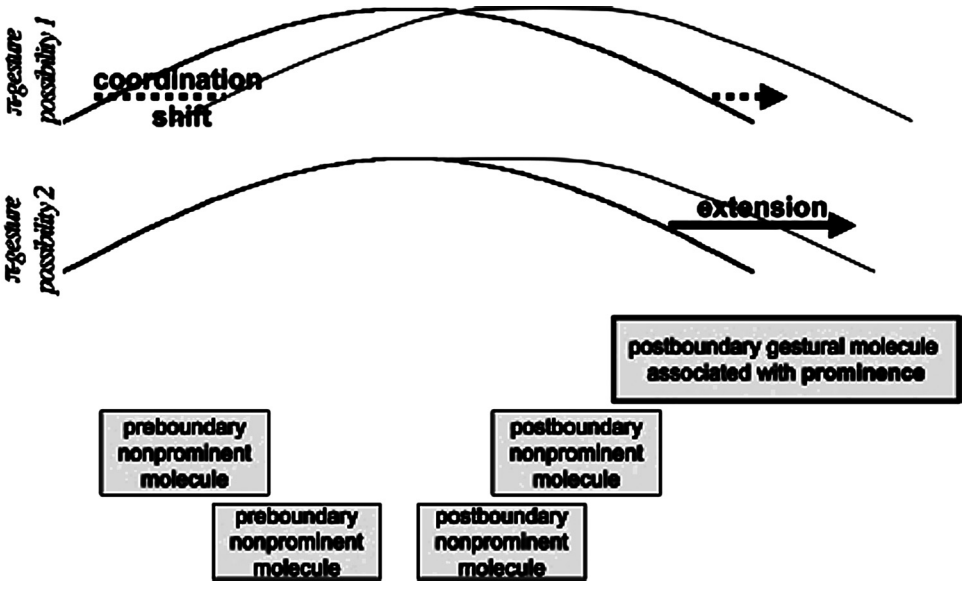


Figure 4 Two possible π-gesture organizations in the presence of a prominent phonological event.

would not change in magnitude, but the OVERALL amount of boundary-induced lengthening would be predicted to increase. (This could be quantified perhaps by integrating under the FDA time-deformation functions outlined in Lee, Byrd & Krivokapić 2006.) Finally, while both accounts could be consistent with the finding that constrictions between the phrase edge and the prominent material lengthen, the extension account would require such a finding; while the shift account, if the shift were dramatic enough and the π-gesture brief enough, could accommodate a situation in which intervening unstressed material showed little or no lengthening. The present study suggests the need for such a follow-up examination of the articulation of intervening unstressed material at a boundary. Such studies are currently underway in our laboratory.

Importantly, regardless of whether it is the edge-extension or coordination-shift account that receives future experimental support, the results presented above suggest the importance of further empirical data addressing the possibility that the temporal activation pattern of π-gestures – or equivalently the temporal pattern of local-rate-warping at prosodic boundaries – is not always limited to phrase-edge-adjacent articulations. Articulatory results from Krivokapić (2007b) on the scope of boundary lengthening even in the absence of prominence suggest likewise. Prosodic properties such as lexical stress and pitch accent of the phonological material in the vicinity of a phrase edge may be relevant to the scope of prosodic lengthening at a phrase boundary.

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