Acoustic evidence for the effect of accent on CV coarticulation in Radio News speech

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1. Introduction: phrasal accent and hyperspeech

Lexical stress and phrasal accent condition phonetic variation that is documented in both articulatory and acoustic studies. Sounds that occur in stressed or accented syllables are produced in a manner that can be described as "hyperspeech", following Lindblom (1990). In this mode speech gestures are produced with greater velocity, magnitude, and duration (Beckman & Edwards 1994; Beckman & Cohen 2000). It is also claimed that hyperspeech involves a reduction in coarticulation, with a greater separation between the speech gestures of adjacent sounds (de Jong 1995; de Jong, Beckman & Edwards 1993). In contrast, speech sounds produced in unstressed or unaccented syllables are made with 'smaller' speech gestures and exhibit greater overlap between adjacent gestures than in the stressed/accented condition. The 'hypospeech' mode of unstressed, unaccented syllables results in sounds that are reduced in time and in articulatory space relative to their hyperspeech counterparts. These reductions result in a decrease in the distinctiveness between contrastive sounds in prosodically weak positions.

Hyperspeech effects are documented for English in articulatory studies primarily for the oral gestures that implement the constriction degree and location of consonants and vowels, as in many of the studies cited above. Acoustic studies of hyperspeech effects under stress or accentual prominence are fewer, but there is evidence of strengthening effects in acoustics, too. Acoustic effects of accent are reported in the increased duration of vowels (Beckman & Edwards 1994) and consonants (Turk & White 1999), similar to the lengthening effects reported for lexical stress (Crystal & House 1988; Klatt 1974; Umeda 1977). Phrasal accent also conditions increased VOT values for both voiced and voiceless stops (Choi 2003; Pierrehumbert & Talkin 1992). Spectral evidence of accentual strengthening in English is reported by Wouters & Macon (2002), who show increases in the spectral rate of change in the transitions between vowels and adjacent liquids and glides.

This paper reports on preliminary results from a study of how phrasal accent conditions acoustic variation in the radio news speech. The focus here is on evidence for CV coarticulation in the pattern of second formant transitions in stop-vowel sequences, comparing accented and unaccented CVX syllables. Our study is based on the speech of one professional radio news announcer from the Boston University Radio News speech corpus (Ostendorf et al. 1995).[1] The speech in this corpus differs from "laboratory" speech in several ways. First, it is produced under a meaningful communicative context, where the speaker has a genuine interest in communicating the discourse and lexical content of an utterance through the effective use of acoustic cues to prosodic structure. The speech is also produced in fluent passages that span entire paragraphs and which are much longer than those used for laboratory speech. Second, the speech is produced by a professional announcer who is experienced in reading scripts with fluency. In general, the speech of radio news announcers is described as being clearer and with more consistent indications of prosodic structure than non-professional read speech (Ostendorf et al. 1995). Thus, we expect to find clear indications of prosodic effects at the segmental level in this type of speech, as have been described for laboratory speech. Finally, the speech corpus is not constructed by the experimenter for the purpose of a specific experiment; thus, there is overall greater variation in the local context from which target sounds are taken, and typically unequal

[1] This speech corpus is distributed by the Linguistics Data Consortium [www.ldc.upenn.edu].

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numbers of sounds in the groups being compared. This feature results in 'noisier' data compared to the data from laboratory speech.

The next section discusses the status of locus equations as acoustic evidence to stop place of articulation and CV coarticulation. Section 3 presents the methods and results of our study, and establishes positive evidence for the effect of phrasal accent on locus equation measures of stop place of articulation. Section 4 discusses the results in terms of patterns of paradigmatic strengthening, and offers a brief comparison between accentual vs. positional effects on locus equation measures.

2. Locus equations and coarticulation

Early work by Delattre et al. (1955) shows that F2 transitions provide important cues to the perception of stop place of articulation in synthesized speech. Although F2 transitions vary according to the following vowel quality, the transition seems to 'point' at its onset to a F2 locus value that serves as an index to the stop consonant's place of articulation. A series of studies by Sussman and his colleagues (Sussman 1991, 1994; Sussman et al. 1991, 1993, 1995, 1997) establish the significance of F2 transitions as an index of consonantal place of articulation in speech produced by humans, building on the work of Lindblom (1963). First Lindblom and then Sussman and his co-authors showed that there is a systematic, linear relationship between F2 measured at the onset of voicing following stop release (F2-onset) and F2 measured at the midpoint of the following vowel in a CV sequence (F2-midpoint). This relationship is characterized by locus equations, which define the slope and y-intercept of the straight line regression fits for plots of F2-onset as a function of F2-midpoint. Figure 1 shows an example locus equation scatterplot based on a sparse sample of the data from the radio news announcer speech analyzed here. Data are shown from word-initial CV sequences with labial, alveolar, front velar, and back velar stops produced in the context of three following vowels that differ in backness, and thus in F2. These sparse plots illustrate the findings of Sussman et al. (1991) that the locus equation slope and y-intercept values together effectively serve to discriminate stop consonant

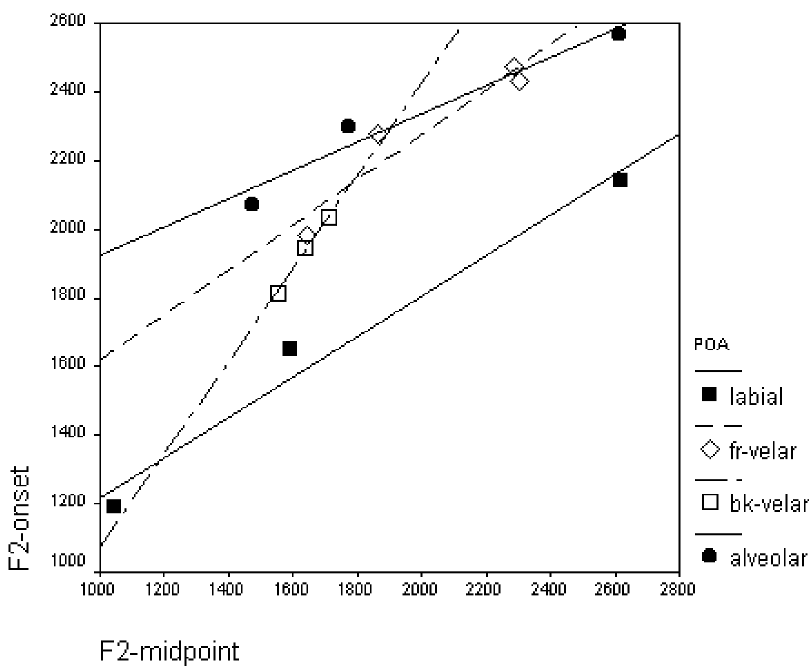


Figure 1. Sample locus equation plots for word-initial voiced stops at four places of articulation, based on 3 word tokens for each place category. The word tokens differ in the backness of the following vowel. The y-axis plots F2 at voicing onset (in Hz) and the x-axis plots F2 at vowel midpoint (in Hz). Regression lines for each place subgroup are shown to differ in slope and y-intercept. Speaker F3A from BU Radio News corpus.

place of articulation. The studies cited above find similar patterns of locus equation slope, with Alveolars < Labials < Velars. Slopes for the back velars are typically close to 1, while slope for Alveolars is closer to .5. Y-intercept values also differ by Place, with Labial < Velar < Alveolar. Sussman et al. (1991) find that locus equation slope and y-intercept values for velars differ depending on the following vowel, and further divide the velar group into front and back velar allophones, based on the front/ back feature of the following vowel.

The F2 value that is taken at voicing onset as part of the locus equation analysis is an indicator of the shape of the oral cavity at a specific point in the transition from the target constriction location of the consonant to that of the vowel. It is therefore in principle sensitive to the phasing of the consonant and vowel gestures. If the consonant and vowel gestures are produced with little coarticulation (a lesser degree of overlap between C and V gestures), then F2 at voicing onset should reflect more of the consonantal constriction location and less of the vowel constriction location. The resulting locus equations will have *less steep* slope than in a comparable sequence produced with more coarticulation (more overlap of the C and V gestures), where F2-onset reflects more of the vowel's constriction location. The prediction is that slope will co-vary with coarticulation: steeper locus equation slope indicates greater CV coarticulation. The idea that locus equations can serve as an index to coarticulation was investigated by Krull (1987, 1989) for Swedish and by Duez (1992) for French. Both authors find evidence of steeper locus equation slopes and shorter CV durations in spontaneous speech compared to read speech, and in unaccented syllables (without sentential stress) compared to accented or stressed syllables. Steeper locus equations and shorter segment durations are interpreted in those works as an indication of more coarticulation. Tabain (2000, 2002) finds partial support for the idea that locus equations serve as an index coarticulation in studies that compare acoustic and EPG data.

In the study reported here, we consider additional evidence for an effect of accent on F2 transitions through a comparison of locus equation measures in accented and unaccented CV contexts in radio news speech. Our predictions for the effect of accent on F2 transitions are based on the findings from articulatory and acoustic studies on the effect of phrasal accent. There are three primary factors beyond C and V identity that influence the F2 transition: C-V overlap, rate of gestural transition, and VOT. Accented CV sequences are found to be produced with lesser CV overlap, faster gestural transitions, and longer VOT. The lesser overlap means that the onset of voicing should occur relatively early in the C-to-V transition, compared to CV sequences with more overlap, as in Figure 2a. An opposite effect is expected from faster gestural transitions under accent; all other factors being

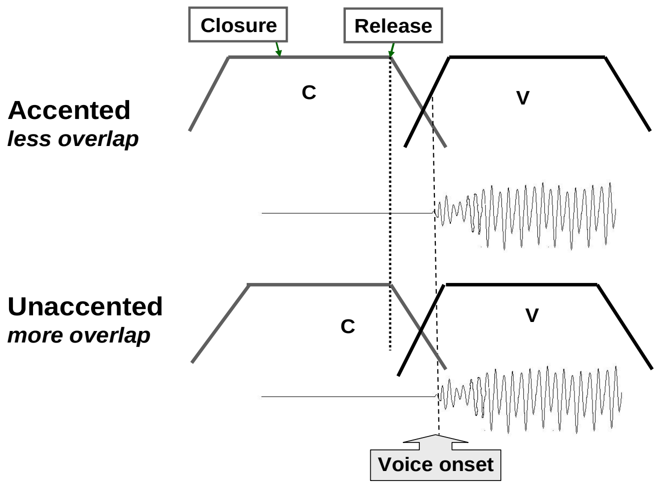


Figure 2a. Schematic diagram of C and V gestures showing less inter-gestural overlap in the Accented condition (top) than in the Unaccented condition (bottom). The locus-equation F2-onset measure is taken at the location marked by voice onset.

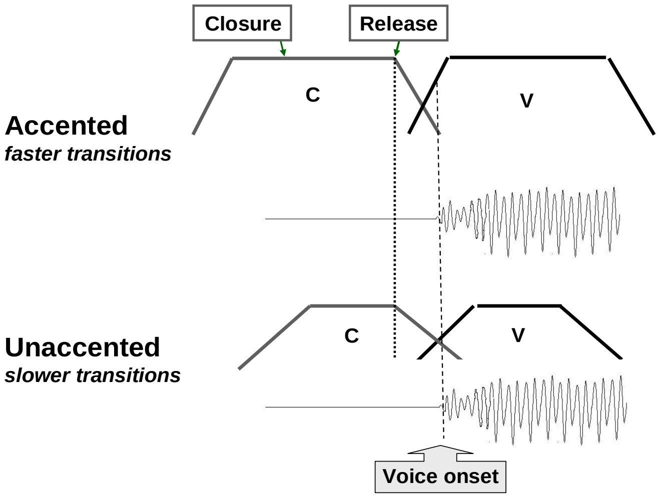


Figure 2b. Schematic diagram of C and V gestures showing faster inter-gestural articulatory transitions in the Accented condition (top) than in the Unaccented condition (bottom).

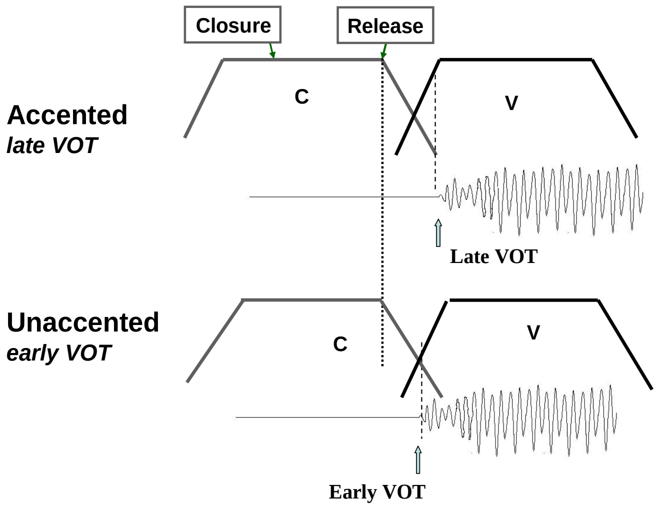


Figure 2c. Schematic diagram of C and V gestures showing later onset of voicing relative to the stop release in the Accented condition (top) than in the Unaccented condition (bottom).

equal, the F2-onset location should occur later in the C-to-V transition, as in Figure 2b. Longer VOT should have a similar effect in ‘pushing’ the F2-onset location later in the transition, as in Figure 2c, and has been shown to be positively correlated with locus equation slope (Engstrom & Lindblom 1997).

The overall effect of accent on F2 transitions depends all of these three factors, and locus equation data can shed some light on the effect of accent on each factor and their interaction. We sketch here three scenarios for the interaction of the three factors and their expected effect on locus equation slope.

Scenario 1: less steep LE slope under accent. The overlap factor predicts locus equation slope will be less steep under accent, but a finding of lower slope values under accent would also indicate that the combined influence of gestural transition rate and VOT was not sufficient to counteract the effect of decreased overlap. Under this scenario, the decrease in locus equation slope serves as an index to lesser coarticulation between the oral C and V gestures.

Scenario 2: steeper LE slope under accent. The transition rate and VOT factors predict increased slope under accent, and such a finding would mean that those two factors outweighed any effect from decreased C-V overlap. It's important to note that a finding of increased slope under accent doesn't support the conclusion that gesture overlap remains constant under varying accent conditions, but only that any difference in overlap due to accent is not sufficient to counteract the opposing effects from transition rate and VOT. Note that an increase in VOT in the absence of a decrease in C-V overlap means that the onset of voicing occurs later in the vowel gesture, i.e., there is more coarticulatory overlap between the *oral* and *laryngeal* gestures. Thus, under this scenario, increased slope values may mark an increase in laryngeal-oral coarticulation, but do not provide clear evidence for inter-oral (CV) coarticulation.

Scenario 3: no LE slope difference under accent. A finding of no difference in locus equation slope could mean either no significant effects of accent on any of the factors, or equally balanced effects from overlap and transition rate-plus-VOT. As with scenario 2, the null effect of accent on locus equation slope does not provide clear evidence of degree of inter-oral CV coarticulation.

An additional effect of accent reported in prior work is that of *paradigmatic strengthening,*wherein phonological contrasts are enhanced under accent (Cho 2001; Choi 2003; de Jong 1995; Lindblom, 1963). With respect to the present study, we expect to find evidence of paradigmatic strengthening under accent in increased distance between contrastive place categories in the acoustic space defined by locus equation slope and y-intercept. Finally, a further mechanism for contrast enhancement would be the production of speech gestures with less variability, which should result in locus equation regression lines with higher correlation coefficients (higher *R2* values).

3. Methods

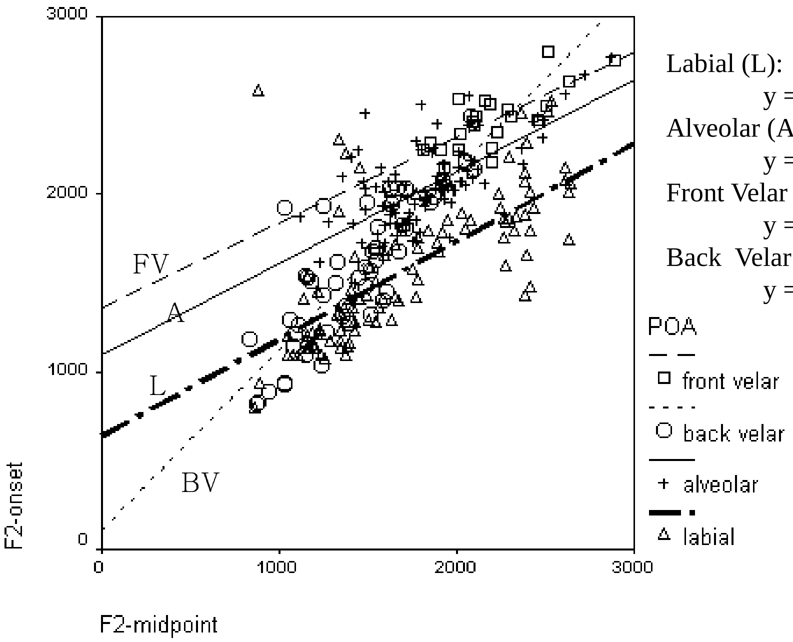
Locus equation data analyzed in this study are taken from the speech of one female professional radio news announcer (speaker F3A) from the Boston University Radio News corpus. The data consist of word-initial stop-vowel sequences. The database is labeled for prosodic structure using the ToBI labeling standard (Beckman & Ayers 1994), based on Beckman & Pierrehumbert's (1986) model of intonation for American English. The prosodic labeling marks pitch accent on syllables that have phrasal prominence, phrase boundaries at four levels of prosodic juncture, and phrase tones that occur at boundary locations. Our study is focused on the effect of phrasal accent on CV transitions, and so the CV tokens analyzed here are identified as accented (bearing a phrasal pitch accent) or unaccented on the basis of the ToBI labeling. Table 1 shows the distribution of stop consonants analyzed in this study according to their place of articulation and accent label. Front and back velars are separated into two groups, following Sussman et al. (1991).

	Labial	Alveolar	Front Velar	Back Velar	Total
Voiced	64	29	11	7	111
voiceless	36	75	11	45	167
Total	100	104	22	52	278

Table 1. Distribution of target stop consonants for locus equation analysis in this study, according to voicing and place of articulation

3.1 Measurements

All acoustic segmentation and measurement was done using Praat software for speech analysis (Boersma & Weenink 2002). F2 values were taken based on Praat's automatic formant analysis using



Labial (L):
$y = 0.65x + 410.26$
Alveolar (A):
$y = 0.514x + 1093.5$
Front Velar (FV):
$y = 0.48x + 1359.39$
Back Velar (BV):
$y = 1.016x + 10.15$

Figure 3. Locus equation regression lines for four POA groups of consonants, pooling over voicing and accent categories. Locus equation slope and y-intercept are shown at the right.

the Burg algorithm with 5 formants. F2-onset measurements were taken at the visible beginning of the second formant in the wide-band spectrogram for both voiced and voiceless stops. An alternative approach of measuring F2-onset immediately following burst release was attempted but was found to result in an excessive number of invalid F2 measurements. F2-midpoint measurements were taken at the visually determined vowel midpoint. Extreme outlier F2 measurements were hand-corrected using visual analysis of the spectrogram.

3.2 Results

A locus equation plot of F2-onset against F2-midpoint for all stop tokens combined, under both accent conditions, is shown in Figure 3. A linear regression line is fit to each POA subgroup, yielding the values of slope and y-intercept shown to the right of the plot. Although the data for the four POA groups overlap significantly in this acoustic space, the locus equation lines show distinctive values for slope and y-intercept. The ranking of the POA groups by slope is FrontVelar < Alveolar < Labial < BackVelar; and by y-intercept is BackVelar < Labial <Alveolar < FrontVelar. The ranking of the POA groups by slope and by y-intercept is consistent with the findings of Sussman et al. (1991) for the relationship between labials and alveolars, and between front and back velars, but differs in the relationship between labials and back velars, and between alveolars and front velars. Sussman et al. report no significant differences in slope between labial and back velar and between alveolar and front velars, but finds significant y-intercept differences of Labial < Back Velar < Alveolar < Front Velar. A noticeable difference between our data and the locus equation results from laboratory speech, such as those of Sussman and his colleagues, is in the lower $R2$ values for the correlation coefficient in radio news speech. The $R2$ values for the locus equation regression lines in Figure 2 are: Labials $R2$ = .495; Alveolars $R2$ = .456; Front Velars R2 = .567; Back Velars $R2$ = .677. These values are substantially lower than the $R2$ values reported by Sussman et al., which (for the single speaker for which the statistic is reported) range between .6 and close to 1.

To assess the effect of accent on locus equation measures, each POA group is plotted individually, with separate regression lines fit to accented and unaccented tokens. The results are displayed in Figures 4a-d. and the values of locus equation slope, y-intercept and R2 for the regression lines are shown in Table 2. Slopes are steeper and y-intercepts are lower under accent for all four POA groups, indicating that there is a greater influence of the vowel’s F2 on the F2 at voice onset for accented CV than for unaccented CV. *R2* values are greater under accent for all POA groups except back velars, indicating that in accented CV more of the variation in F2-onset variation is attributable to F2-midpoint than in unaccented CV.

(a) **(b)**

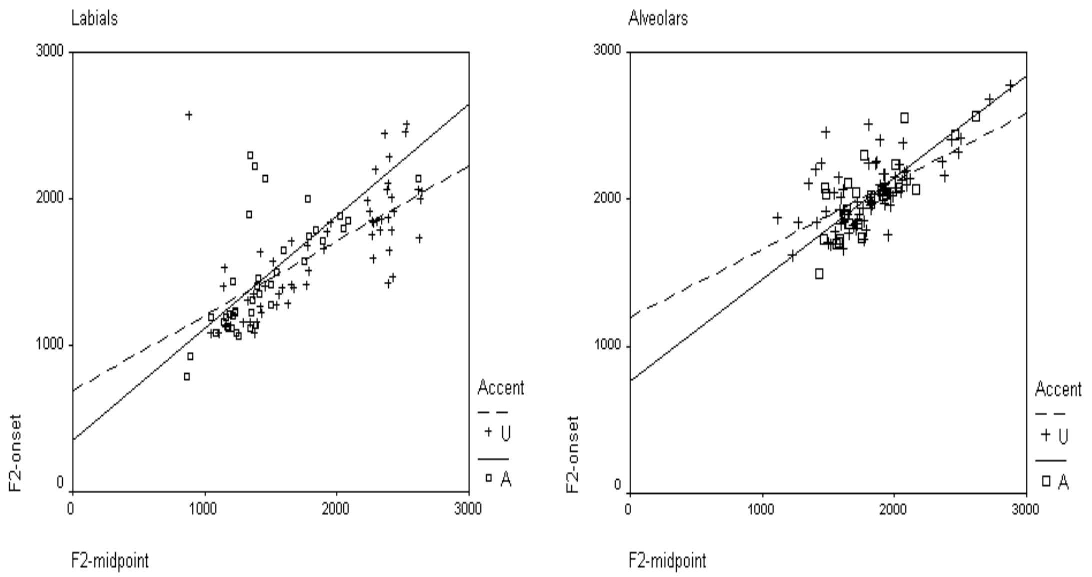


Figure 4a-b. Locus equation regression lines for accented and unaccented labials (a, left) and alveolars (b, right).

(c) **(d)**

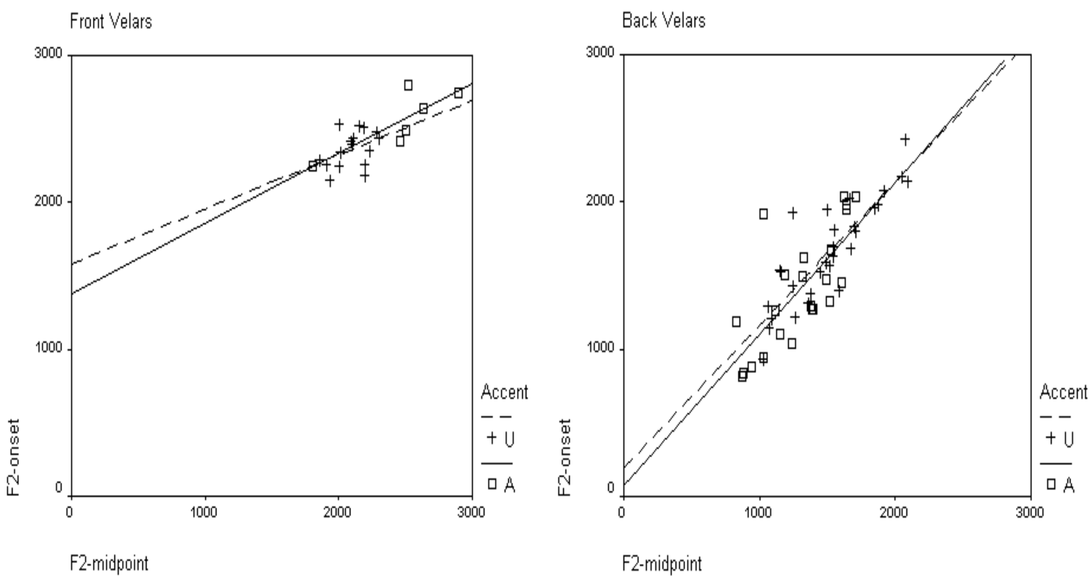


Figure 4c-d. Locus equation regression lines for accented and unaccented front velars (c, left) and back velars (d, right).

	Accented			Unaccented		
	Slope	y-intercept	R^2	Slope	y-intercept	R^2
Labials	0.787	256.295	0.791	0.659	365.111	0.729
Alveolars	0.692	762.238	0.602	0.461	1194.336	0.418
Front Velars	0.477	1381.14	0.672	0.370	1584.05	0.163
Back Velars	1.029	72.10	0.537	0.971	194.62	0.739

Table 2. Slope, y-intercept and *R2* values for the locus equation regression lines in Figures 4a-d.

The final set of results relates to the separation among the POA categories in F2 acoustic space under accented and unaccented conditions. Figures 5a,b show locus equation plots for all POA groups combined, for accented and unaccented conditions. A visual comparison of these plots does not suggest any greater separation of the POA groups in the accented condition. Figure 6 plots locus equation slope against y-intercept, in a second-order locus equation plot. The spacing of these data points is not greater under accent.

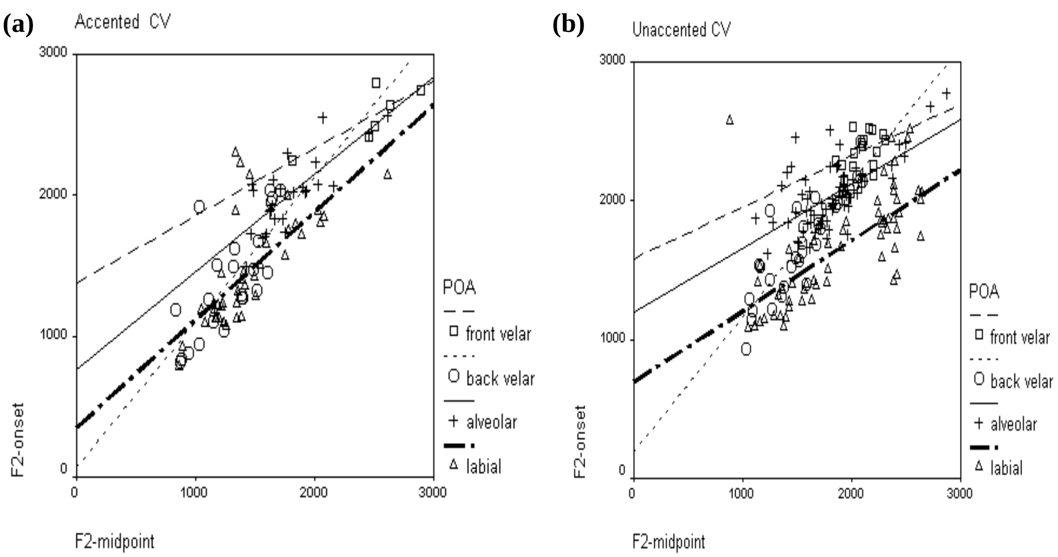


Figure 5a-b. Locus equation regression lines plotted for all accented stops (a, left) and all unaccented stops (b, right).

4. Discussion

Our first finding in this study is that the labial, alveolar, front velar and back velar places of articulation have different patterns of F2 transition as measured by locus equations. The differences in slope and y-intercept values among the POA group in this study closely resemble the locus equation patterns reported in earlier work for laboratory speech. Our method differs from that of Sussman et al. (1991) and others in that our locus equation measures are based on sets of tokens that combine voiced and voiceless stops. For comparison purposes we performed locus equation regression fits to voiced and voiceless stops separately, for all POA groups except the back velars (for which there were too few voiced tokens). The voiced and voiceless groups differed in each case, but the overall ranking of POA groups by slope and y-intercept remained the same, both within each voicing category, and when pooling voice categories together. For each POA group, the voiceless stops had higher slope and lower y-intercept than the corresponding voiced stops. This is the expected difference, since the voiceless stops have greater VOT than the voiced stops, which means that the F2-onset measure is

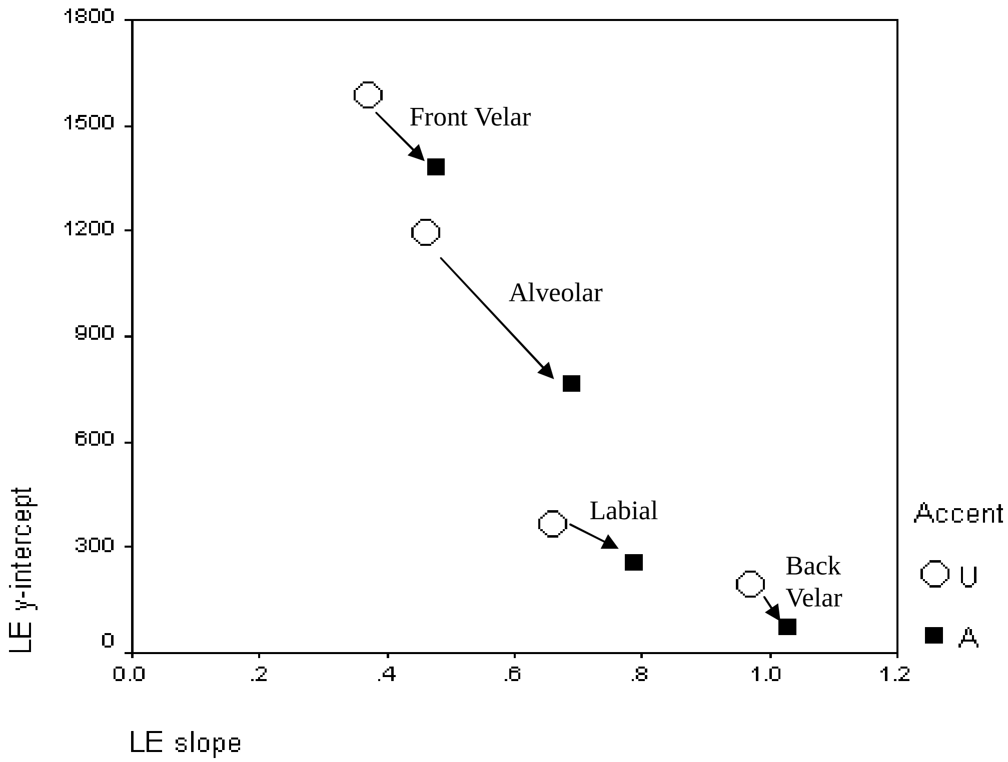


Figure 6. Plot of locus equation y-intercept as a function of slope, showing the separation among the POA categories in F2 space under accented and unaccented conditions.

located later in the C-to-V articulatory transition for the voiceless stops. Late F2-onset results in steeper locus equation slope, as discussed in section 2, so the voiceless stops are predicted to have steeper slope than the voiced, as observed here. Generally speaking, the slope of the POA group with combined voiced and voiceless tokens is very close to the mean of the slopes for the separate voiced and voiceless subgroups.

The main difference between the radio news speech analyzed here and the laboratory speech of prior studies is in the amount of F2 variation that can be accounted for under the locus equation model. That amount, measured by the correlation coefficient *R2*, is much greater in laboratory speech, indicating that there are other major sources of variation in radio news speech that affect the F2 transition in CV sequences. We expect that these differences may stem from the extreme clarity that is typical of laboratory speech, but less so of radio news speech (and even less so of spontaneous, conversational speech). A related observation is that there is a great degree of overlap between the POA groups in locus equation F2 space. Thus, although locus equation values do differ between the groups, it seems unlikely that the F2 values at voice onset and vowel midpoint would be sufficient evidence for POA classification. It is more likely that POA cues from F2 transitions are integrated with other cues for POA, such as burst spectrum, burst amplitude, and closure duration.

Accent is observed to have a measurable effect on locus equation slope and y-intercept. Steeper slopes and lower y-intercepts under accent indicates that the F2 value at voice onset is strongly influenced by the vowel in an accented CV sequence, more so than in an unaccented CV. Krull (1987, 1989) and Duez (1992) claim that steeper slopes are indicative of a greater degree of CV coarticulation, and specifically that the vowel has a greater coarticulatory influence on the preceding consonant. Under this view, our findings would seem to indicate **greater** coarticulation in accented syllables, contrary to expectations based on prior studies. But this interpretation of our findings must be tempered by the recognition that VOT is also significantly affected by accent, and exerts a separate influence on F2 onset. As discussed in section 2, longer VOT results in a F2-onset value that is farther along in the articulatory C-to-V gestural transition, and therefore more indicative of the vowel's target F2 value. In fact, we have evidence of a large and statistically significant effect of accent on VOT, with increases for both voiced and voiceless stops under accent for this speaker (Cole et al. 2003). If there is in fact reduced CV coarticulation under accent for this speaker, then it must be the case that the effects on F2 are not sufficient to counteract the opposing influence of increased VOT. In the presence of the VOT effect from accent, our finding of steeper slope can not be simply interpreted in terms of a difference in coarticulation alone.

The four POA groups are not observed to have a greater separation in F2 space under accent; the slope and y-intercept values that serve to distinguish POA groups are not more distinct from one another under accent. Given this, we find no evidence of paradigmatic strengthening of the F2 transitional cues to POA under accent. Accent has a similar affect on F2 transitions for all POA groups, with similar outcomes for locus equation slope and y-intercept. This finding suggests that contrast enhancement is not the primary goal of accentual strengthening, at least not for the POA dimension of phonological contrast. Our finding of no contrast enhancement under accent can be compared to the findings of Sussman et al. (1997), comparing locus equation measures for CV *vs.* VC transitions. They report steeper locus equation slope, less variability in F2 measures, and better contrast enhancement in CV compared to VC. In our comparison of accented *vs.* unaccented CV transitions, we find steeper slope, and higher R2 values (consistent with lesser variability), but no evidence of contrast enhancement. We conclude that the effect of contrast enhancement must be independent of slope effects, and that the effect of accent on CV coarticulation is not identical to the effect of syllable position.

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