

# An Acoustic and Electropalatographic Study of Lexical and Post-lexical Palatalization in American English\*

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## 1 INTRODUCTION

In American English, alveolar obstruents (/t, d, s, z/) become palatoalveolars (/tʃ, dʒ, ʃ, z/) before the (palatal) glide /j/. Palatalization is obligatory at the lexical level, as illustrated by pairs such as *habit/habitual*, *grade/gradual*, *confess/confession*, and *please/pleasure*. Palatalization also appears to apply, optionally, at the post-lexical level, as in the phrases *hit you*, *made you*, *press your point*, and *please yourself*. This paper argues, however, that lexical and post-lexical palatalization are two different processes, requiring two different representations.

Other investigators have noted that a similar process, palatalization of /s/ before /j/, may be gradient when it applies across word boundaries (Catford, 1977; Shattuck-Huffnagel, Zue, & Bernstein, 1978; Zue & Shattuck-Huffnagel, 1980; see also Hulst & Nolan, in press, for British English). In the experiment reported here, acoustic and electropalatographic (EPG) data contrasting lexical and post-lexical palatalization of /s/ before /j/ were collected. The data show that palatalization of /s/ before /j/ is also gradient when it applies across word boundaries, while lexical palatalization is categorical. It is argued here that the articulatory patterns found in post-lexical palatalization suggest overlapping gestures, as in the theory of Articulatory Phonology (Browman & Goldstein, 1986, 1990, 1992). In a departure from Articulatory Phonology, however, it is further argued that lexical palatalization is best described in terms of features, and a mapping

between features and gestures is suggested. Sections 2 and 3 discuss the methods and results of the experiment. Section 4 turns to the question of how the categorical and gradient rules should be represented.

## 2 Methods

**2.1 Stimuli.** Stimuli for this experiment contrasted underlying alveolars and palatoalveolars with both lexically-derived palatoalveolars and alveolar + /j/ sequences occurring across a word boundary (Table 1A). Data for /t/, /d/, /s/, and /z/ were collected, but only the data for /s/ are analyzed here. In the alveolar + /j/ sequences, /j/-initial pronouns and content words were contrasted, and the boundary between alveolar and glide was varied (phrase break vs. none). Each condition was represented by two different lexical items, divided into sets 1 and 2. In order to obtain information on the articulation of /j/, data from a second set of lexical items was also collected, in which the first consonant in the sequence was a labial (Table 1B). Within each set, the preceding vowel and the stress pattern remained constant across conditions.

Each lexical item was placed in a sentence. For presentation to the subjects, sentences were randomized within sets, over all consonants. For each subject five different randomizations of each set were created.

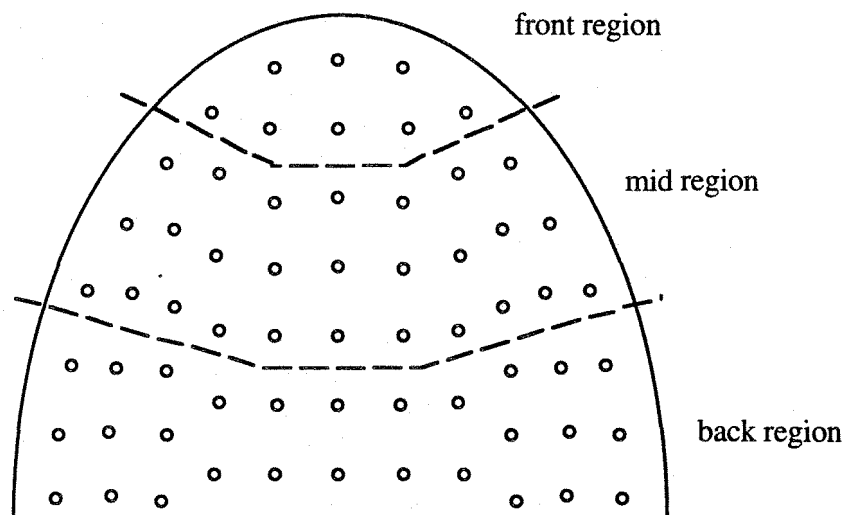
**2.2 Data collection and analysis.** Three native speakers of American English participated. Acoustic and EPG data were recorded simultaneously, using the Rion palatography system (Shibata, Ino, Yamashita, Hiki, Hiritani, & Sawashima, 1978). In this system, palates are not custom made; rather, the best fit is chosen from six available sizes. The arrangement of electrodes on the palate is shown in Figure 1. One data frame (the 63 electrodes sampled in sequence) is recorded every 15.6 ms.

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**Table 1.** Stimuli contrasting underlying /s/, /ʃ/, and /j/ with lexically-derived /f/ and /s#j/ sequences.

A. Fricatives:	SET 1	SET 2
1. underlying /f/	mesh on	fresh analysis
2. underlying /s/ + /t/	confess to	press together
3. underlying /s/ + /t/, phrase break	confess, to	impress, to get
4. lexically-derived /f/	confession	impression
5. underlying /s/ + /i/	messy	dressy
6. /s/ + you	confess you	press you
7. /s/ + you, phrase break	confess, you	press, you
8. /s/ + your	confess your	press your
9. /s/ + your, phrase break	confess, your	press, your
10. s/ + /j/-initial content word	confess unitedly	press uranium
11. /s/ + /j/-initial content word, phr. break	confess, uniting	press, uranium
<b>B. Palatal glide:</b>		
1. /b/ + you	stab you	
2. /b/ + you, phrase break	stab, you	
3. /b/ + /j/-initial content word	stab Eugene	
4. /b/ + /j/-initial content word, phrase break	stab, Eugene	

**Figure 1.** Arrangement of electrodes on the palate, showing the division into front, mid, and back regions.

In the acoustic analysis of the fricative tokens, the centroid of the fricative noise was computed for each EPG frame. (The centroid is the weighted average, based on amplitude, of all the frequencies present in the spectrum of fricative noise.) The times indicating the beginning and end of each EPG frame were marked in the acoustic signal,

which was digitized at 20,000 samples/second. For each token, the spectrum of the fricative noise was computed from the first EPG frame showing full frication to the last, using a 12.8 ms Hamming window at 1 ms intervals. Centroid values over a range of 500 to 10,000 Hz were then computed for the window in the center of each EPG frame.

In the EPG analysis, patterns of palate contact for lexically-derived /j/ and for the /s#j/ sequences were compared with patterns of contact in utterances containing underlying /s/, /j/, and /j/. The series of EPG frames that made up each fricative or glide articulation was isolated on the basis of the articulatory patterns. For each control utterance (underlying /s/, /j/, and /j/: 1 - 3 in Table 1A for the fricatives and 1 - 4 in Table 1B for /j/), an empirically-determined target pattern for the articulation was then located. Target was deemed to have been reached when the pattern of articulation remained stable over several frames (see Zsiga, 1993 for details). These target patterns formed the basis of templates, to which the other articulatory patterns were compared in terms of front, mid, and back contact.

### 3 Results

**3.1 Acoustic results.** Clear differences in the centroid values for the different fricatives were found. Figure 2 displays data for several sample utterances. These figures show the centroid values

at each frame for five repetitions of underlying /s/, underlying /j/, derived /j/, and an /s#j/ sequence, aligned at the last frame of frication.

Figure 2A displays the centroid values for /s/ (in *press together*) and /j/ (in *fresh*) for subject 1. The two fricatives are clearly distinct, and divide the figure into two regions, above 5200 Hz for /s/ and below 5200 Hz for /j/. Lexically-derived /j/ (Figure 2B) falls completely within the /j/ region. The pattern is different, however, for /s#j/ (Figure 2C). In the phrase *press your*, the centroid values begin like /s/, but fall into the /j/ region by the end.

Figure 2D-F shows the same contrasts for subject 2. As can be seen in Figure 2D, this subject shows even greater separation between /s/ (in *confess to*) and /j/ (in *mesh*). Figure 2E shows that the /j/ in *confession* is not different from the /j/ in *mesh*. The /s#j/ tokens, however, show a lot of variation, and often a large change over time. While all are fully in the /j/ range by the end of the fricative, at the beginning tokens are either /s/-like, or in between /s/ and /j/.

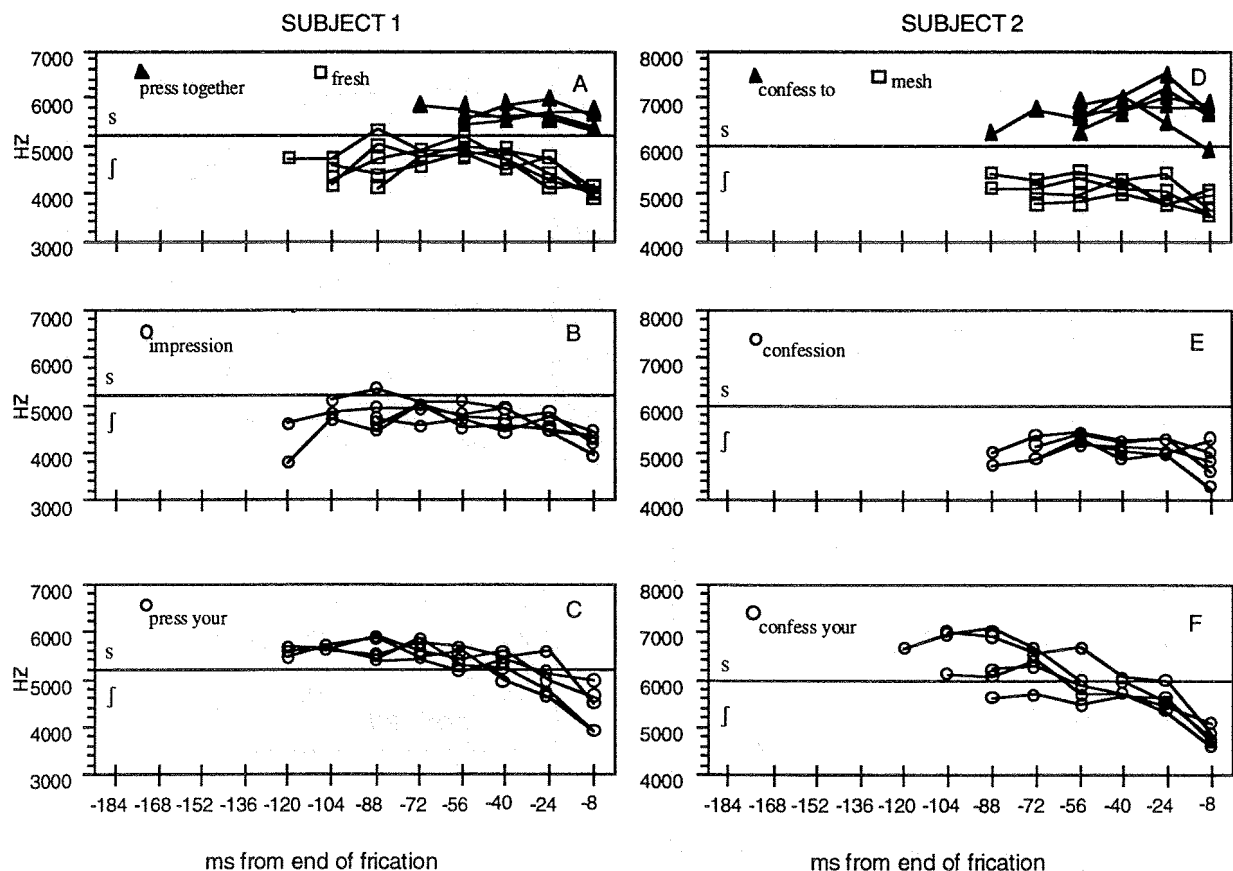


Figure 2. Centroid values for several sample utterances.

For statistical analysis, centroid values for all of the fricatives were compared at three points: the first frame of frication (onset), the last frame of frication (end) and the third to last frame of frication (-3 frames). The third from last, rather than the middle, frame was chosen for analysis because, as Figure 2 shows, the effect of a following articulation begins to be evident near the end of the fricative, but not necessarily half-way through. The hypotheses to be tested were (1) that lexically-derived /ʃ/ does not differ from underlying /ʃ/ and (2) that the /s#j/ sequences show partial palatalization, evidenced by falling centroid values over the course of the fricative.

These hypotheses were tested by comparing /s#j/ and lexically-derived /ʃ/ to underlying /s/ and /ʃ/ at the three measurement points. The two underlying fricatives are predicted to differ at each measurement point. It is predicted that lexically-derived /ʃ/ will not be distinct at any point from underlying /ʃ/, while the /s#j/ sequences will show a gradient change, with values not distinct from /s/ at the first frame, not distinct from /ʃ/ at the last frame, and possibly distinct from both /s/ and /ʃ/ at the third from last frame. Figure 3 shows the mean values for each subject for underlying /s/ (in

*dressy* and *messy*), underlying /ʃ/ (*fresh*, *mesh*), derived /ʃ/ (*impression*, *confession*), and /s#j/ (averaged across all conditions with no phrase break). The /si/ rather than /s#t/ sequences were used in these comparisons to control for differences at the end of the fricative that might be due to the effect of a following stop rather than a more open articulation.

As is evident in Figure 3, the fricative types were different overall, and they differed in the way their values changed over time. In a repeated measures analysis of variance, with factors set, fricative type, and frame, each subject showed a highly significant effect of fricative type, and of the interaction between fricative type and frame. (No subject showed a significant 3-way interaction of fricativeXsetXframe.) As there was a significant effect of fricative for each subject at each frame, a Tukey test was used to analyze which fricatives differed from which at each of the three points. The predicted and actual contrasts among the different fricative types are shown in Table 2. In the table, conditions not significantly different at the .05 level are separated by an = sign, and where relevant (subject 3, end) are enclosed in identical bracketing.

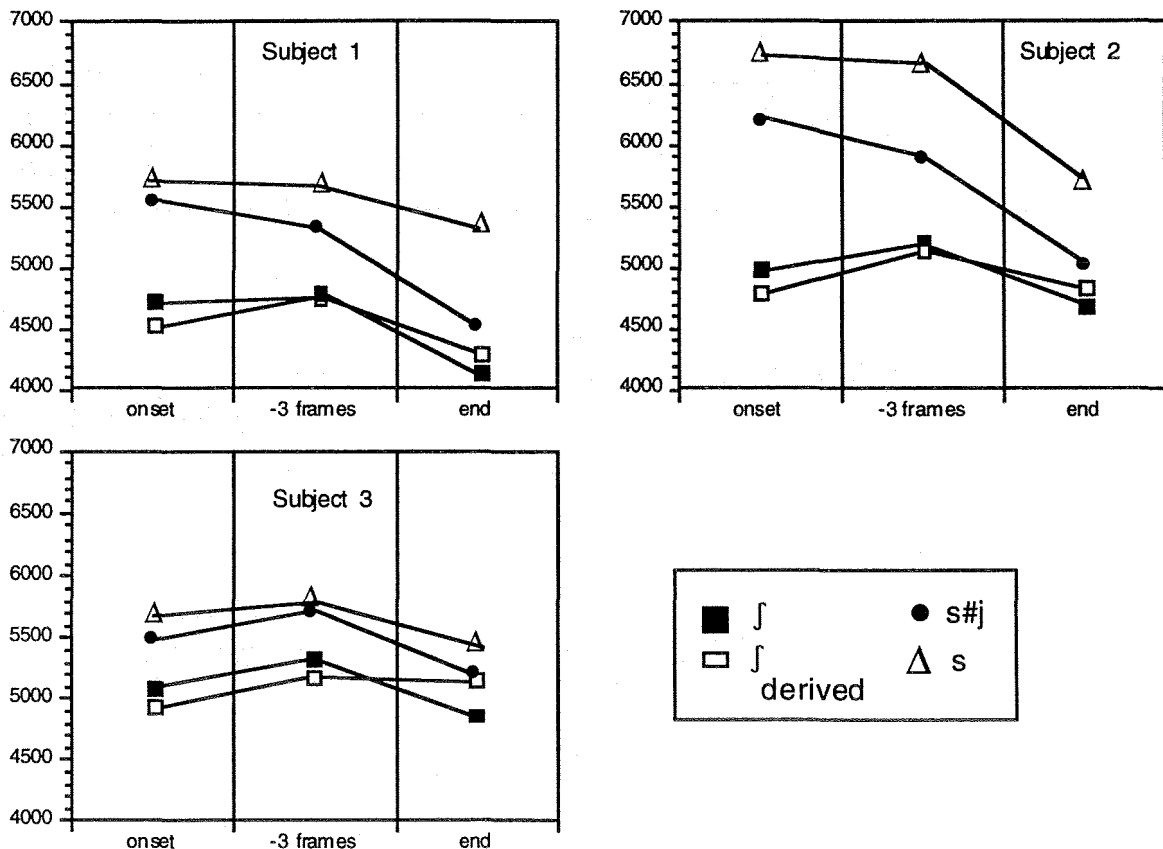


Figure 3. Mean centroid values for four fricative types.

**Table 2.** Predicted and actual contrasts in centroid values at onset, -3 frames, and end for four fricative types.

	onset	-3 frames	end
predicted:	s = s#j > f-derived = f	s > s#j > f-derived = f	s > s#j = f-derived = f
Subject 1:	s = s#j > f-derived = f	s > s#j > f-derived = f	s > s#j > f-derived = f
Subject 2:	s > s#j > f-derived = f	s > s#j > f-derived = f	s > s#j = f-derived = f
Subject 3:	s = s#j > f-derived = f	s = s#j > f-derived = f	(s = [s#j = f-derived] = f)

Underlying /s/ and underlying /j/ were distinct at all three points for all three subjects. Underlying /j/ and derived /j/ were not distinct at any point for any of the subjects. The centroid values of these fricatives tended to be lower at onset and end (where amplitude was also lower) than at -3 frames.

In the /s#j/ sequences, subjects 1 and 2 fit the predicted pattern almost perfectly. For both subjects, although the centroid value for /s/ is lower at the end of the fricative than at -3 frames, the value for the /s#j/ sequences is lower still. For subject 1, there is substantial change over the course of the fricative in a /s#j/ sequence: at onset, /s#j/ is not significantly different from /s/; at -3 frames, /s#j/ falls in between /s/ and /j/, and is significantly different from both; and at the end frame, /s#j/ is much closer to /j/ than to /s/, although a significant difference remains between the sequence and underlying /j/. Subject 2 also shows a large change over time. The /s#j/ sequence falls in between /s/ and /j/ at both onset and -3 frames, although it is closer to /s/ at onset. At the end of the fricative, /s#j/ is not distinct from /j/.

Results for subject 3 are less clear. Centroid values for underlying /s/ and /j/ were more similar for this subject than for the other two, and overlapped to a greater extent. While the /s#j/ sequence shows lower values than /s/ throughout, it is not significantly different from underlying /s/ at any of the three points. At the end frame /s#j/ fell in between /s/ and /j/, but is not significantly different from either. Note, however, that derived /j/ is also not significantly different from /s/ at the end of the fricative. Derived /j/ and /s#j/ have nearly identical values at this point, and even the difference between /s/ and underlying /j/ was significant at the .05, but not the .01, level. This convergence of values at the end of the fricative makes the results for this subject difficult to interpret. He does show a tendency for /s#j/ centroid values to become /j/-like at the very end of the fricative, but because the values for /s/ and /j/ at this point are so close, /s#j/ and /s/ are not significantly different. It may be that placement of

the palate interfered with articulation for this subject (see section 3.2).

Overall, these acoustic results show that lexical palatalization is categorical. There is no acoustic difference between underlying and derived /j/. For /s#j/, palatalization is gradient, in two senses. First, /s#j/ shows substantial change over time, from /s/-like at the beginning to /j/-like at the end. Second, the acoustics for the /s#j/ utterances may show centroid values intermediate between /s/ and /j/ throughout the fricative. As could be seen in Figure 2, there is considerable token to token variation in the /s#j/ sequences. Some begin like /s/ and fall over time, some are /j/-like throughout, others are in between the two. While lexical palatalization is categorical and obligatory, post-lexical palatalization is both gradient and variable in its application.

The next section turns to the patterns of articulation, and how these patterns are correlated with changes in the acoustics.

**3.2 EPG results.** Contact patterns at target for /s/, /j/, and /j/ for each subject are shown in Figure 4. For /j/, patterns are based on the steady state portion of the articulation in *mesh* and *fresh*, for /s/ in *confess to* and *press together* with no phrase break, and for /j/, in *stab you* both with and without phrase break. The number of times each electrode was activated at target over ten tokens is shown. Electrodes activated in 80% or more of the tokens are outlined. For the most part, the patterns shown here are qualitatively similar to those reported in earlier studies (e.g. Recasens, 1984, 1990; Hardcastle & Clark, 1981; Hardcastle, Gibbons & Nicolaidis, 1991). Some differences are discussed below.

For quantitative comparison, the palate was divided into three regions: front, comprising the first two rows; mid, comprising the middle three rows; and back, comprising the back three rows (see Figure 1). A one-way analysis of variance was performed on the target frames for each subject and region, with utterance as the independent variable and the number of electrodes activated within each region for each token as the

dependent. The utterance effect was highly significant ( $p < .001$ ) for all subjects and regions, except for front contact for subject 3, where the effect just reached significance ( $p = .036$ ). A Tukey test was then performed to determine which articulations were significantly different in each region. Very few differences were found due to the presence or absence of a phrase break, or to set. The /j/ in *eugene*, however, was found to show substantial coarticulation with the following affricate, and so is not used as a template (see

Zsiga, 1993 for discussion). Differences between underlying /s/, underlying /ʃ/, and /j/ in *you* are summarized in Table 3. Differences not significant at the .05 level are separated by an = sign.

For subject 1, the target patterns are as expected for alveolars, palatoalveolars, and a palatal glide. The /s/ articulation shows more front contact and less back contact than any other: it is the only articulation showing contact in the frontmost row. /ʃ/ differs from /s/ in having less front contact, and from /j/ in having less back contact.

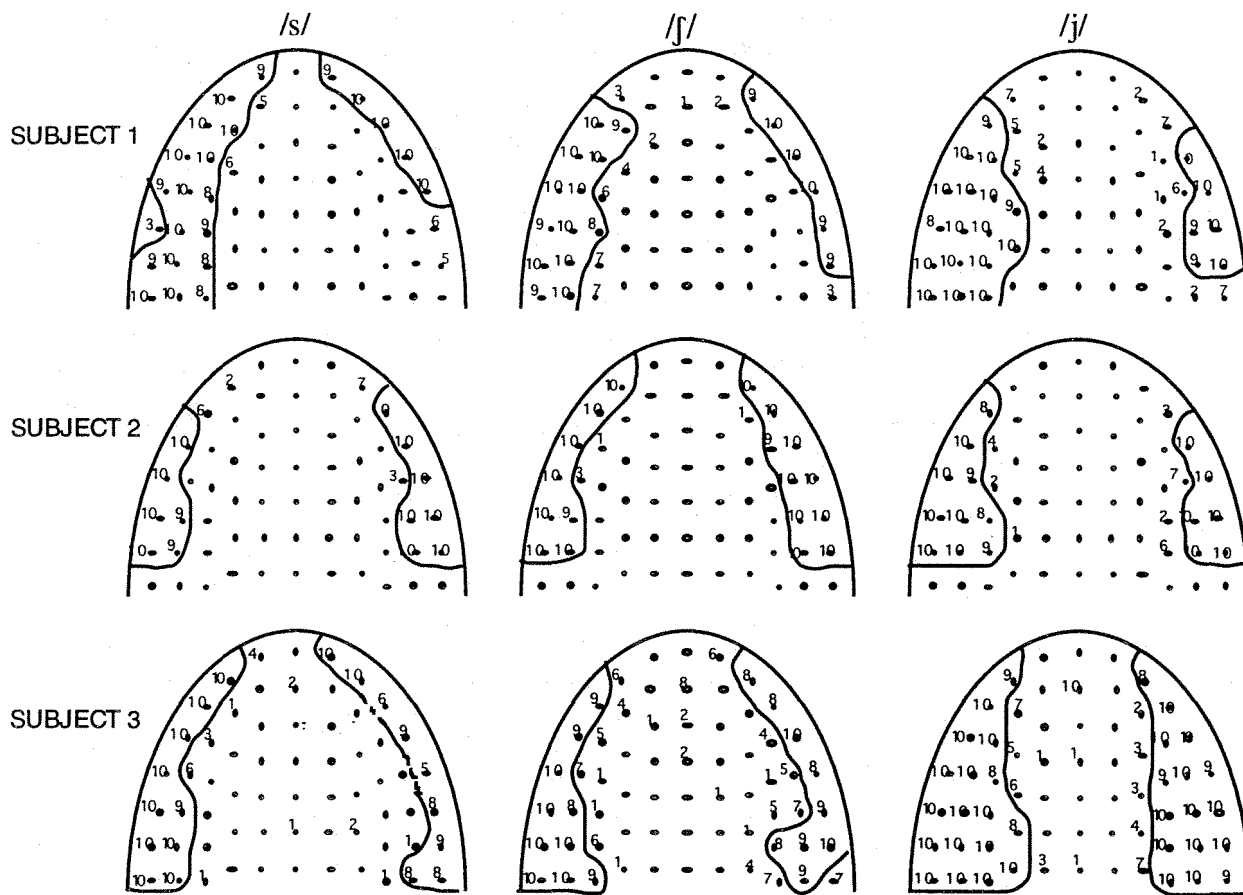


Figure 4. Target patterns for underlying /s/, /ʃ/, and /j/ for each subject, based on a steady-state portion of the articulation.

Table 3. Differences in the number of electrodes activated at target in each region of the palate for each subject.

	S1	S2	S3
front region	$s > f = j$	$f > s = j$	$s = f = j$
mid region	$s = f = j$	$f > s = j$	$s = f = j$
back region	$s = f < j$	$s = f < j$	$s < f < j$

For subject 2, while /s/ and /ʃ/ show a significant difference in the amount of front contact, unexpectedly /ʃ/ shows the greater contact in this area. For this subject, the artificial palate was probably set slightly too far back, and failed to record contact at the frontmost edges of the subject's palate. (Recall that this subject showed the greatest acoustic difference between the two fricatives.) Due to the reversal in the amount of front contact for /s/ and /ʃ/ for this subject, and the fact that the two articulations do not differ in the amount of back contact, it is not clear that the patterns for /s/ and /ʃ/ can be reliably distinguished, nor is it clear how a /s#j/ sequence is predicted to differ from an underlying /ʃ/.

Subject 3 showed the least consistent patterns of articulation. As discussed above, his acoustic patterns were also problematic. Many electrodes are activated in fewer than half of the articulations. Several isolated electrodes, particularly in the center of the palate, appear to remain activated after release. (This can occur when the mouth is too dry.) For this subject, the articulations are clearly distinguished only in the back region.

Because of the difficulties in distinguishing the patterns in the control utterances for subjects 2 and 3, the rest of this discussion will focus on the articulatory data for subject 1. See Zsiga (1993) for a full discussion of all three subjects.

The patterns for underlying /s/, /ʃ/, and /j/ serve as templates for examining /s#j/ and derived /ʃ/. Figure 5 illustrates, for subject 1, how the patterns of activated electrodes in derived /ʃ/ (from *confession* and *impression*) and /s#j/ (from *press*

*you* and *confess you*) change over time. Filled dots indicate those electrodes activated in at least 8 of 10 repetitions at the first frame of frication, the third to last frame, and the last frame. (Grayed electrodes were on 7/10 times.) Just as the acoustics do not change over time for derived /ʃ/, the pattern of palate contact remains stable throughout the whole fricative. The pattern for /s#j/, however, does not follow that for /ʃ/. At the onset of frication, there is very little contact at the back and center of the palate, but over the course of the fricative central and back contact fills in.

Figure 6 shows the pattern of electrodes for derived /ʃ/ and *s+you* at one point in time: -3 frames (the middle column in Figure 5). In each column of Figure 6, templates from the /s/, /ʃ/, and /j/ control utterances (corresponding to the outlined areas in Figure 4) are overlaid on the palate patterns. In the first column the template for underlying /ʃ/ is overlaid. This template corresponds almost exactly to the pattern for derived /ʃ/. For *s+you*, however, the /ʃ/ template is not a good fit: there is too much contact at the front and center of the palate. This poor fit illustrates that although the acoustics in the *s+you* sequence at this point in time may be /ʃ/-like, the articulation is not. Rather, as the set of template patterns in the second column shows, the pattern in the *s+you* sequence is what would be expected from an /s/ and /j/ being articulated at the same time. While the /s/ and /j/ templates do not fit the derived /ʃ/ articulation, they do account well for the front and central contact in the *s+you* sequence.

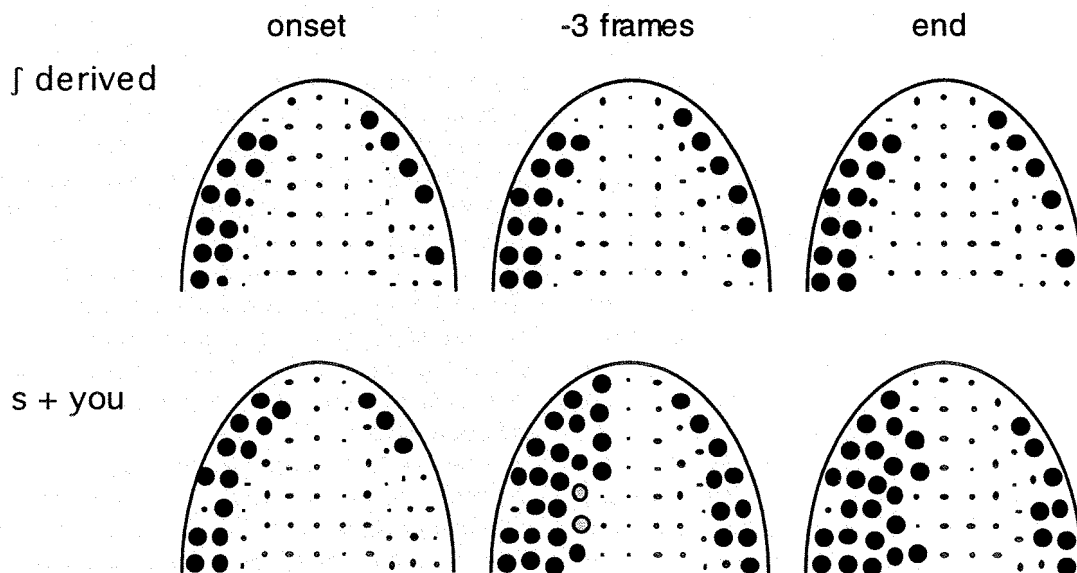


Figure 5. Change in contact patterns over time, subject 1. Electrodes shown were activated in at least 8 of ten repetitions.

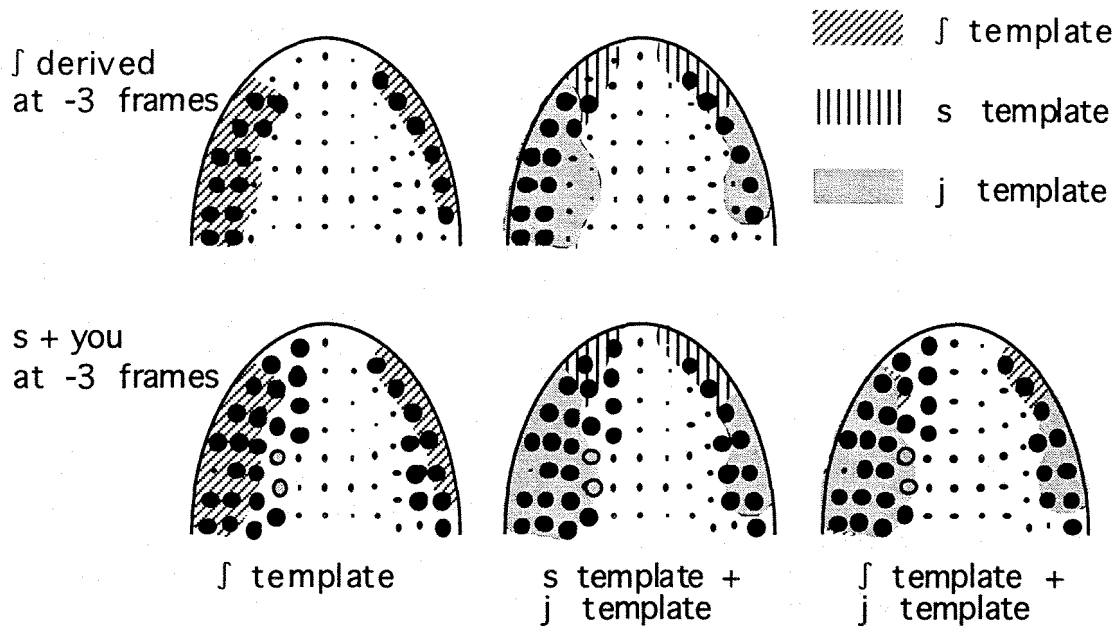


Figure 6. Templates from underlying /s/, /j/, and /j/ overlaid on the patterns for *s+you* and derived /j/ at -3 frames.

Although not all the *s+you* electrodes are covered by the templates, it is likely that the tongue, if it made contact at both the front and back regions at the same time, would cover the areas of those electrodes as well. In the third column, the /j/ and /j/ templates are overlaid on the *s+you* pattern. It might have been the case that /s/ did undergo a categorical change to /j/, and that the difference in the patterns seen in Figure 5 was due only to the fact that the following consonant is /j/ in one case but /n/ in the other. However, the combination of the /j/ and /j/ templates could not account for the pattern of front contact seen for *s+you*. It is the pattern produced by the overlap of /s/ and /j/ that fits the *s+you* articulation at -3 frames most closely.

Finally, a significant correlation was found between the acoustic and articulatory measures. The centroid values at onset, -3 frames, and end were correlated with the total number of electrodes activated in the front and back regions at those points. For subject 1, the amount of back contact accounts for 28% of the variance in the centroid values, and front and back contact, taken together, account for 45% of the variance (both significant at  $p < .01$ ). Back contact, not front contact, better determines the centroid value. As contact in the back region increases, the centroid value falls. These findings are consistent with the hypothesis that in the /s#j/ sequences, increased overlap of the /s/ and /j/ gestures, and therefore

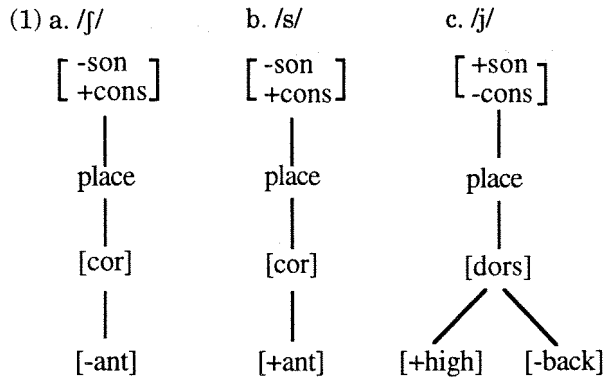
more back contact during the fricative, leads to the lower centroid values.

#### 4 Discussion

This experiment has shown a clear difference between lexical and post-lexical palatalization in American English. Post-lexical palatalization is gradient and variable. Lexical palatalization, on the other hand, involves a categorical alternation between /s/ and /j/: underlying and derived /j/ were not found to differ either acoustically or articulatorily. (The data presented here is consistent with the view that the coronal fricative in *confession* in fact *is* an underlying /j/. It will be assumed here, however, that the regular lexical alternations relating words such as *confess* and *confession* should be expressed in the grammar as phonological rules.) This section examines the question of how the two different kinds of palatalization should be represented. Representations using autosegmental features and articulatory gestures are compared. It will be argued that both representations are needed: phonological features best capture categorical alternations, articulatory gestures best capture gradient processes.

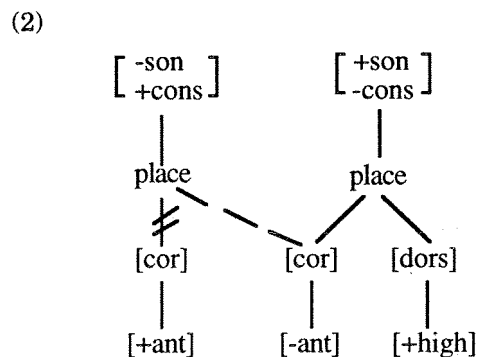
Consider first the featural representation. The featural representation of American English palatalization is bound up with the question of the best way to represent palatal consonants and glides. In the feature geometries argued for in

Sagey (1986) and McCarthy (1988), /s/ and /j/ are represented with the feature [ant] as a dependent of the [coronal] node (1a, 1b). The glide /j/ is represented with the features [+high] and [-back] as dependents of the dorsal node (1c).



Borowsky (1986) formalizes /s#j/ palatalization as spreading of [+high] from the glide to the alveolar. In this formalization, a dorsal node to which the feature can attach must be interpolated, and then a special implementation rule must be invoked to interpret the resulting configuration as phonetically identical to that in (1a).

However, recent studies, both phonological (Clements, 1976, 1991; Hume, 1990, 1992; Broselow & Niyondagara, in press; Ní Chiosáin, 1991) and phonetic (Keating, 1988), have argued that /j/ should be analyzed as having a coronal component. (For an opposing point of view, see Recasens, 1990, this volume.) The representation of palatalization in (2) follows Keating in representing /j/ as a complex segment with both coronal and dorsal components. The [-ant] coronal component spreads from the glide to the alveolar, effecting a categorical change from /s/ to /j/.



As will be argued below, however, this representation is not appropriate for gradient palatalization.

Consider instead the gestural representation. The articulatory evidence presented here (at least

for the subject for whom clear results can be obtained) suggests that gradient palatalization can be represented in terms of gestural overlap (following Browman & Goldstein, 1986, 1990, 1992). The palatal constriction for /j/ overlaps in time with the alveolar constriction for /s/ when /s/ and /j/ are adjacent at a word boundary. The combination of front contact due to the /s/ gesture and increasing back contact due to the /j/ gesture results in centroid values that fall over the course of the fricative.

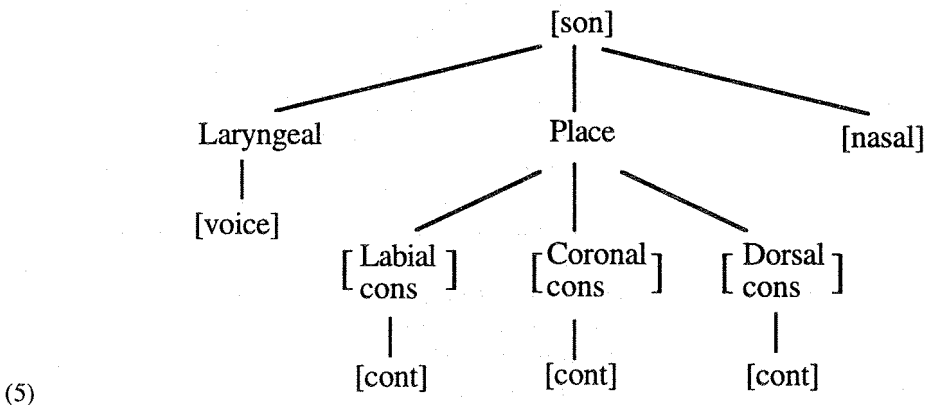
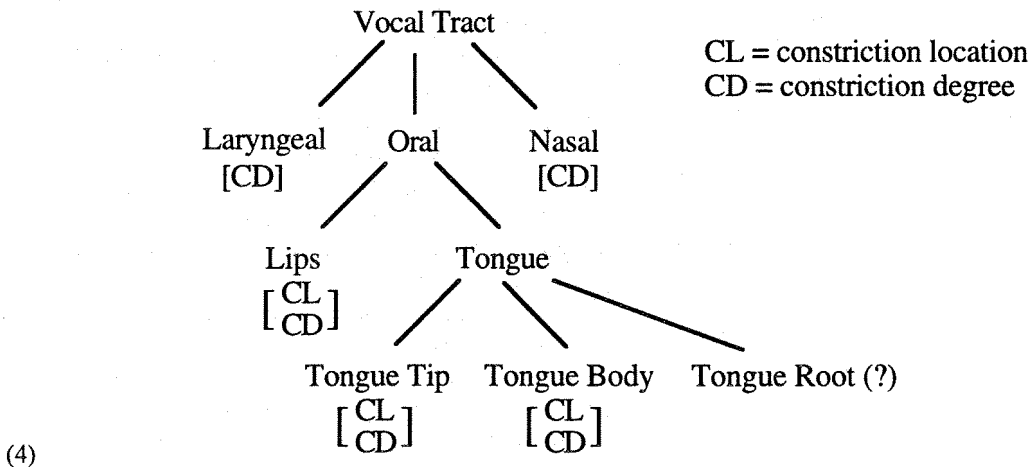
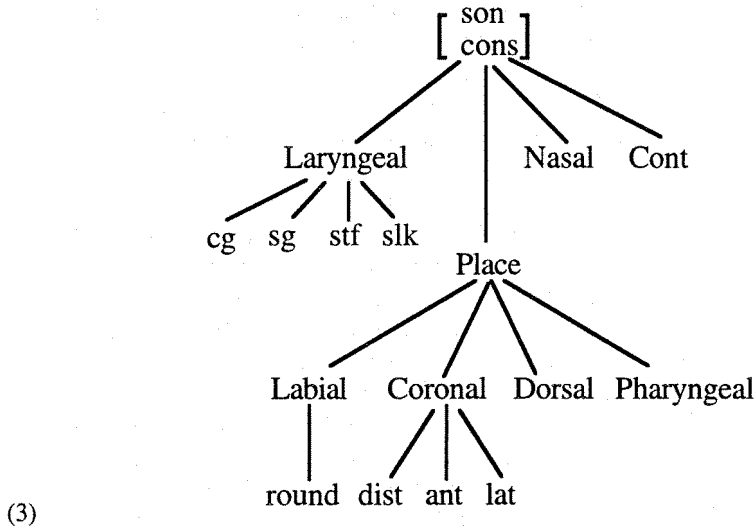
The gestural representation captures the gradience and variability seen in post-lexical palatalization. For the period of time before the /j/ gesture begins, the articulation and acoustics will be that of a simple /s/. As overlap with the /j/ increases, the articulatory and acoustic influence of this gesture also increase. Many instrumental studies have demonstrated overlap among speech gestures (e.g. Hardcastle, 1985; Hardcastle & Roach, 1977; Öhman, 1966; Perkell, 1969; and Marchal, 1988). Zsiga (1994) provides evidence for substantial overlap between consonant gestures at word boundaries in English. It may be that the pattern of overlap seen here is just that typical of the overlap between any two consonants at a word boundary. If so, then no post-lexical rule of palatalization is required. The effect of palatalization would simply be the acoustic consequence of the normal pattern of overlap.

Both categorical and gradient palatalization can be seen as the imposition of the high tongue position for the glide onto the consonant. In categorical palatalization, the [-ant] coronal feature spreads from one root node to the next. In gradient palatalization, the /j/ gesture overlaps in time with the /s/ gesture.

The featural and gestural representations in fact correspond very closely. Compare the autosegmental representation in (3), argued for in McCarthy (1988), with (4), the "functional anatomy of the vocal tract" presented in Browman and Goldstein (1989). Both representations are based on articulators: the lips, the tongue tip, the tongue body, and possibly the tongue root. (See Browman & Goldstein, 1989; McCarthy, in press for discussion of the representation of pharyngeal articulations.) In both the gestural and the autosegmental representations, the nasal, laryngeal, and oral subsystems are separated. Browman and Goldstein (1989) have pointed out that the convergence on a single geometry from the direction of phonological patterning and from the direction of phonetic function provides strong support for the geometry's essential correctness.

There is an even more striking similarity to the feature geometry proposed in Padgett (1991). Padgett argues, on the basis of patterns of assimilation, that [continuant] and [consonantal] should be specified for each articulator, in an "articulator group", as shown in (5). These two features then correspond directly to the constriction degree and stiffness specified for each

gesture. (In Articulatory Phonology, stiffness encodes the difference between vowels, glides, and consonants.) While smaller differences between the two geometries remain to be resolved (see Zsiga, 1993), a straightforward correspondence between the feature [labial] and a labial closing gesture, between the feature [nasal] and a velum opening gesture, etc., is evident.



Despite this close correspondence, the representations can not be collapsed. The different way that timing is expressed in the two representations makes features appropriate for expressing lexical contrasts and categorical alternations, and gestures appropriate for expressing gradient processes. Consider two simple examples that illustrate this point: the first example deals with lexical contrasts, the second with phonological rules.

Compare the gestural and autosegmental representations of a labiovelar stop in Figure 7. Figure 7A shows an autosegmental representation, Figure 7B a gestural representation. Both representations involve two articulators: lips and tongue body (labial and dorsal). The most basic difference in the representations is how temporal organization is expressed. Features do not have specific durations, and the only temporal relations that can be defined in this representation are linear precedence and an unspecified amount of overlap (see Bird & Klein, 1990; Sagey, 1988). Association among features is expressed by linkings to abstract hierarchical nodes. Features associated to a given hierarchical node (and not on the same tier) are assumed by the phonology to overlap in time, but the degree of overlap remains unspecified. Thus, there can be no contrast be-

tween two kinds of labiovelars that differ only in timing: labial closure followed by dorsal ( $/b\hat{g}/$ ) and dorsal closure followed by labial ( $/g\hat{b}/$ ).

In contrast, gestures have inherent extent in time. Precise overlap relations can and must be specified, and are crucial for describing articulatory patterns. Organization among gestures is expressed through the direct specification of timing relations (phasing) between two or more gestures, not through linkings to abstract nodes. In the theory of Articulatory Phonology, phase relations can in themselves serve as the basis of phonological contrast: for example, the difference between aspirated and unaspirated stops is encoded in the phase relations between the glottal and oral gestures (Goldstein & Browman, 1986). Given that several different phasings are possible between the labial and tongue body gestures in a labiovelar stop, there is no reason the phase differences could not serve as the basis of lexical contrast. Thus Articulatory Phonology predicts a possible contrast between  $/b\hat{g}/$  and  $/g\hat{b}/$ . The same holds true (as Clements, 1992 points out) of phasings between glottal opening and oral gestures. A gestural representation predicts many possible contrasts, for example between pre-aspirated, unaspirated, and post-aspirated stops, when in fact no language has more than a two-way contrast.

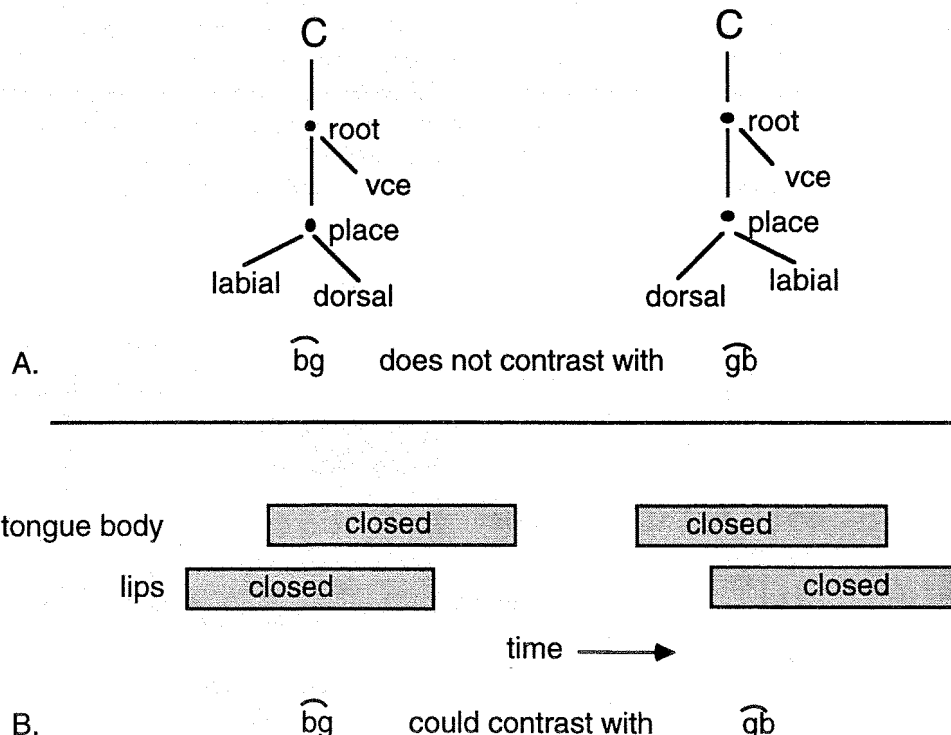


Figure 7. Representations of a labio-velar stop. A. Featural. B. Gestural.

In fact, /g̃b/ (dorsal closure first, labial closure second) is almost invariably chosen as the articulatory organization (Connell, 1991; Maddieson & Ladefoged, 1989). As Connell (1991) points out, the phase relations among the different component gestures are crucial for understanding the phonetic behavior of these stops, as well as their diachronic development. Therefore, a phonetic representation must be able to express the asymmetry of the dorsal and labial gestures. But any phonological representation that has the power to express that timing relationship makes wrong predictions about possible synchronic phonological contrasts. It also makes wrong predictions about possible phonological rules.

Consider two rules of nasalization, one categorical, the other gradient. Categorical nasalization can be represented as spreading of the feature [nas] from consonant to vowel (Figure 8A). Because there is no way for a feature to spread only part way from one root node to another, the result is categorical assimilation. To express partial nasalization, explicit timing must be taken into account.

Figure 8B shows a gestural representation of partial nasalization. Because gestures have extent in time, specific points in one gesture are timed with respect to specific points in another gesture. In this gestural score, maximum velic opening is timed to occur at the beginning of the tongue tip gesture for the final /n/. (Krakow, 1989 found this timing relation to hold of nasalized vowels in American English.) In order to achieve this timing with respect to the consonant, the velum opening gesture must begin during the vowel, resulting in partial nasalization. A gestural representation can also capture complete nasalization, by specifying a

different timing relation. The vowel and the velum opening could begin at the same time, so that nasalization extends throughout the vowel.

The gestural approach thus uses the relation of overlap in time to describe complete as well as partial processes. Yet specific timing is unnecessary for the description of synchronic phonological rules. In the lexical component, where all rules are categorical, and where reference to abstract hierarchical nodes like the root node is necessary, a theory that allows specific temporal relations to be manipulated is too powerful. While specifying timing relations among gestures is appropriate for gradient rules, categorical rules require the all-or-nothing, plus-or-minus specification that feature spreading provides. However, because the two representations are so similar in respects other than timing, the mapping between them is straightforward. Gestural scores can be seen as feature trees with elaborated timing information, or feature trees can be seen as gestural scores underspecified for temporal relations.

This paper has argued for two different representations for lexical and post-lexical palatalization: an autosegmental featural representation for the categorical lexical rule and a gestural representation for the gradient post-lexical rule. Articulators form the basis for both representations. They differ principally in the kind of temporal information that is available for manipulation: specific extent in time for gestures, only simultaneity and precedence, expressed in terms of linking to hierarchical nodes, for features. This simple correspondence between features and gestures leads to a simple correspondence between categorical and gradient rules.

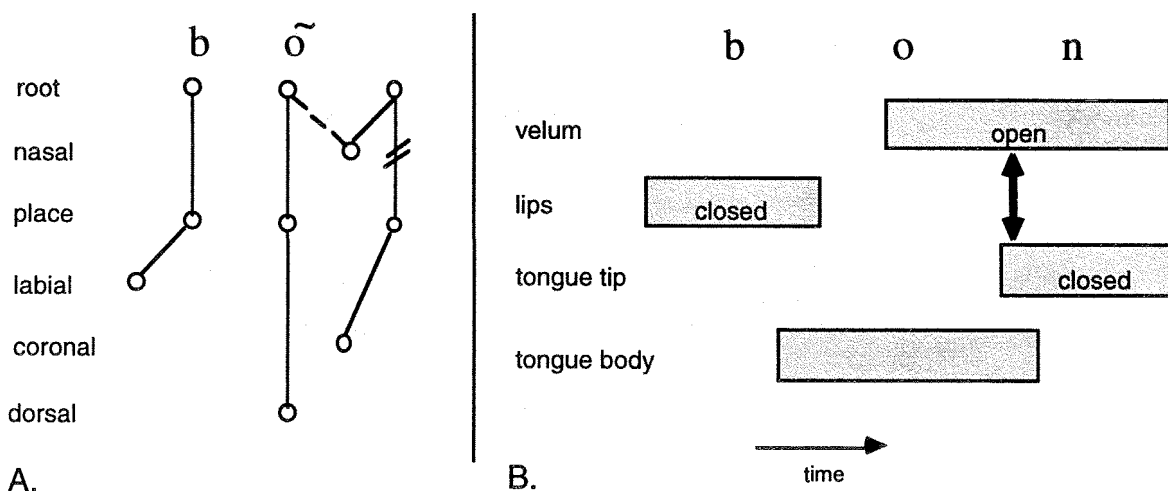


Figure 8. Two rules of nasalization. A. Categorical. B. Gestural.

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## FOOTNOTES

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