881

NONSEGMENTAL INFLUENCES ON VELUM MOVEMENT PATTERNS: SYLLABLES, SENTENCES, STRESS, AND SPEAKING RATE

RENA A. KRAKOW

Department of Speech-Language-Hearing
Temple University
Philadelphia, Pennsylvania 19122
and
Haskins Laboratories
New Haven, Connecticut 06511

1. INTRODUCTION

Investigations of the motor organization of speech show that if we can identify individual segmental requirements, we can begin to predict the manner in which segments will influence each other in fluent speech. That is, we can model coarticulation as the outcome of temporal overlap (coproduction) among characteristic speech movements for successive segments (e.g., Bell-Berti & Harris, 1981; Fowler, 1980; Munhall & Löfqvist, 1992; Saltzman & Munhall, 1989). Support for a coproduction model has largely been drawn from studies of articulators that shape the oral tract (the lips, jaw, tongue) or of formant frequencies that reflect oral tract shape (cf. Bell-Berti & Harris, 1981; Boyce, 1988; Fowler, 1980; Öhman, 1966; Saltzman & Munhall, 1989). However, recent work on the velum provides additional strong support for this framework (Bell-Berti & Krakow, 1991a).

Studies of velic movement patterns provide evidence for a segmental level of organization, with *n*-ary values of velic height ranging from extreme low to extreme high positions. These differences in intrinsic velic height are attributable

Phonetics and Phonology, Volume 5
Nasals, Nasalization, and the Velum

not only to whether a segment is nasal or oral, and whether it is a vowel or a consonant, but to such factors as vowel height, consonant place, manner, and voicing (cf. Bell-Berti, 1980; Bell-Berti, this volume; Bell-Berti & Hirose, 1975; Clumeck, 1976; Henderson, 1984; Matisoff, 1975; Moll, 1965; J. Ohala, 1971, 1975; Ushijima & Sawashima, 1972). Velic gestural patterns in sequences of segments also show that there is temporal overlap among the characteristic movements for adjacent segments (Bell-Berti, 1980; Bell-Berti & Krakow, 1991a).

In a number of studies of velum movement, a failure to recognize that oral segments could vary in their intrinsic velic requirements resulted in the identification of the earliest onset of velic lowering in a CV_nN sequence (C = an oral consonant; V_n = any number of phonemically oral vowels; and N = a nasal consonant) as the onset of velic coarticulation for the nasal consonant (e.g., Benguerel, Hirose, Sawashima, & Ushijima, 1977; Bladon & Al-Bamerni, 1982; Kent, Carney, & Severeid, 1974; Moll & Daniloff, 1971). However, further research showed that velic lowering is also observed in the transition from a consonant to a vowel in phonemically oral CV_nC sequences, because oral vowels have intrinsically lower velic positions than oral consonants (e.g., Bell-Berti, 1980; Clumeck, 1976; Henderson, 1984; Ushijima & Sawashima, 1972). Still, it is often the case that velic lowering for a phonemically oral vowel or vowels in a CV_nN sequence is temporally overlapped with the larger lowering gesture for the nasal consonant, rendering the discrete movement components indistinguishable. Adding time between the oral consonant and the nasal consonant, by inserting additional vocalic segments and/or by slowing the rate of speech, reduces the overlap between the shallow velic lowering gesture for the vowel(s) and the more extreme lowering for the nasal consonant (Bell-Berti & Krakow, 1991a).

Identification of a segmental level of gestural organization and an understanding of the manner in which gestures for successive segments combine provide only a partial understanding of the nature of speech motor organization, however, because there are a number of other sources of influence. These include (but are not limited to) variations in syllable structure, syllable location in a phrase or sentence, stress, and speaking rate. Hence, a more complete model of speech motor organization would specify the various nonsegmental as well as segmental influences on the articulators (cf. Fujimura, 1990; Kent & Minifie, 1977; Macchi, 1988; Nittrouer, Munhall, Kelso, Tuller, & Harris, 1988; Vaissière, 1988). Research on the velum shows that the nonsegmental influences are robust and provide additional evidence that the phonetic and phonological functions of the velum are varied and important (Bell-Berti & Krakow, 1991a; Fujimura, 1990; Krakow, 1987, 1989; Vaissière, 1988).

A number of specific examples help to illustrate this point: First, patterns of coordination among velic and labial gestures distinguish syllables with final from those with initial bilabial nasal consonants (Krakow, 1989). Second, velic movement patterns provide support for the notion that declination over the course of a phrase or sentence is not limited to laryngeal-respiratory behavior; similar patterns to those reported for F0 and acoustic amplitude have been found for the jaw, vowel formant frequencies, and for the velum (cf. Bell-Berti & Krakow, 1991b; Gelfer, 1987; Krakow, Bell-Berti, & Wang, 1991; Vatikiotis-Bateson & Fowler, 1988; Vayra & Fowler, 1992). Third, velic movements provide support for the hypothesis raised by Schourup (1973), based on cross-language phonological data, that stress enhances the likelihood of assimilatory nasalization on low levels (cf. Krakow, 1987; Vaissière, 1988). And fourth, velic movement patterns add to our knowledge about how speakers reorganize their gestures to produce speech at a faster rate (Bell-Berti & Krakow, 1991a; Kent et al., 1974; Kuehn, 1976).

This article focuses on nonsegmental influences (syllable organization, syllable position in a sentence, stress, and speaking rate) on velic movements, describing them in terms of characteristic articulatory patterns. The data also indicate a need to incorporate the notion of variable strategies in speech production models, since the evidence suggests that speakers may vary in the manner in which they implement some of these nonsegmental changes (cf. Kent et al., 1974; Kuehn, 1976; Vaissière, 1988). The research described here, combined with studies on the segmental organization of velic gestures (described in Bell-Berti, this volume), call for a much enriched multidimensional model of velic control (see also Bell-Berti, 1980, this volume; Fujimura, 1990; Vaissière, 1988).

2. SYLLABLES

The notion that syllables are units of motor organization goes back at least to 1928, when Stetson proposed that pulses of expiratory muscle activity divide the speech stream into syllable-sized units. Stetson's own data on pulmonary air pressure and his observations of chest wall movement appeared to support this hypothesis (see Stetson, 1951). However, subsequent electromyographic research by Draper, Ladefoged, and Whitteridge (1960) showed that there was no systematic relation between respiratory muscle activity and the syllable. In later studies, the focus shifted from respiratory to articulatory patterns that might correlate with syllable organization. For example, Kozhevnikov and Chistovich (1965) proposed that the articulatory syllable was coextensive with the domain of anticipatory coarticulation and studies of lip protrusion activity provided preliminary support for this hypothesis (e.g., Daniloff & Moll, 1968; Kozhevnikov & Chistovich, 1965; Tatham, 1970). But subsequent work, showing asynchronous coarticulatory domains for different articulators, established the fundamental flaw of this hypothesis (cf. Kent et al., 1974; Kent & Minifie, 1977; Öhman, 1966). That the proposed syllable-based temporal patterns were not generalizable across articulators prompted the question of whether the regularities might rather be found in the patterns of coordination among the articulators (see Krakow, 1989), a suggestion that is consistent with current approaches to characterizing linguistic units in terms of stable patterns of gestural coordination (Browman & Goldstein, 1988; Macchi, 1988; Nittrouer et al., 1988).

The timing of velic gestures relative to gestures that shape the oral tract provides a particularly interesting domain in which to seek stable syllable-based patterns for several reasons. First, the phonetic and phonological evidence suggests that patterns of velic lowering and nasal assimilation are affected by the position of a nasal consonant in a word and hence, possibly in a syllable. Word-final nasal consonants are produced with greater and earlier velic lowering than word-initial nasal consonants, and correspondingly, nasal assimilation is more likely to affect vowels preceding word-final nasals than those preceding or following word-initial nasals (cf. Clumeck, 1976; Fujimura, 1990; Fujimura, Miller, & Kiritani, 1975, 1977; Henderson, 1984; J. Ohala, 1971; Schourup, 1973; Vaissière, 1988). Second, a conflict between studies showing that word boundaries inhibit anticipatory velic lowering and studies showing no word boundary effect can be resolved in favor of an argument for syllable-based patterning (see Krakow, 1989). That is, the studies claiming to find a word boundary effect compared sequences of the forms CV#NV and CVN#V (e.g., J. Ohala, 1971; M. Ohala, 1975), and those that found no effect compared forms such as CVVN and CV#VN (e.g., Moll & Daniloff, 1971). If syllables, rather than words, are relevant and if anticipatory velic lowering is more extensive in syllable-final than syllable-initial nasals, then one would expect to see precisely the patterns reported: that is, less of an effect on the vowel before the nasal consonant in CV#NV than in CVN#V (where a sequence with a syllable-initial nasal is compared to one with a syllable-final nasal) but no difference between CVVN and CV#VN (where two sequences with syllable-final nasals are compared). Third, because the velum functions as an independent articulatory subsystem (see Browman & Goldstein, 1986), the velic lowering gesture for a nasal consonant can, at least theoretically, shift in time relative to the tongue (for /n/) or lip gesture (for /m/) to signal different syllable organizations.

The hypothesis that oral-velic timing patterns for nasal consonants would reveal syllable organization was explored by Krakow (1989). Figure 1 shows the utterance list that was used to investigate syllable- and word-based patterns of labiovelic coordination for bilabial nasal consonants.[1] The stimuli were designed to control segmental influences while providing for the following comparisons: word-initial versus word-final nasals (cols. 2 and 3); syllable-final nasals in word-final versus word-medial positions (cols. 4 and 5); word-medial nasals of unclear syllable affiliation versus word-initial and word-final nasals (col. 1 vs. cols. 2 and 3). For the purposes of this study, no a priori assumptions were made about the syllable affiliation of a nasal consonant in word-medial intervocalic position (or in a CVlNVC sequence).

NASAL CONSONANT POSITION

1	2	3	4	5
Word-Medial	Word-Initial	Word-Final	Word-Final	Word-Medial
homey	hoe me	home E	home Lee	homely
Seymour	see more	seam ore	seam lore	
seamy	see me	seam E	seam Lee	seemly
helmet	hell mitt	helm it	hem lit	hemlette
pomade	pa made	palm aid		

Figure 1. Stimuli for experiment on syllables.

Two speakers produced 12 repetitions of each sequence in a brief carrier phrase. Vertical velic movements were tracked with the Velotrace (Horiguchi & Bell-Berti, 1987) and an optoelectronic tracking system (see Krakow & Huffman, this volume). The tracking system was also used to monitor the time-varying vertical lower lip position, which is influenced by both lower lip and jaw activity. The movement traces were aligned with reference to the onset of bilabial contact for the nasal consonant, a measure derived with the use of an Electrolabiograph.[2] Movement onsets and offsets of the lower lip and velum were determined with the use of the corresponding instantaneous velocity traces. A noiseband around zero velocity (determined for each subject and each articulator) was used for the purpose of eliminating from the measured movements those portions of the movement trajectories that appeared as drift, with velocity values hovering around zero (Krakow, 1989).

Figure 2 provides sample movement patterns for comparison pairs with word-initial vs. word-final nasal consonants. Data from different phonetic sequences and different subjects are used to illustrate the stability of the gestural differences in the two conditions. The vertical line in the middle of each panel marks the onset of bilabial contact. (Lip raising following bilabial contact represents compression of the lower lip against the upper lip.) As shown, the lip movements associated with the bilabial nasal were quite similar for the corresponding word-inital and word-final nasals. In contrast, the velic movements were remarkably different across the word-position manipulation; most obvious, perhaps, is the presence of the long low plateau in the sequences with final nasals and the absence of such a plateau in the sequences with initial nasals. The velum typically reached a lower minimum position for the word-final nasals as well. Considering the coordination between the lip and velum, it can be seen that, regardless of the effects of segmental context and/or speaker, there were two distinct and stable patterns, one asso-

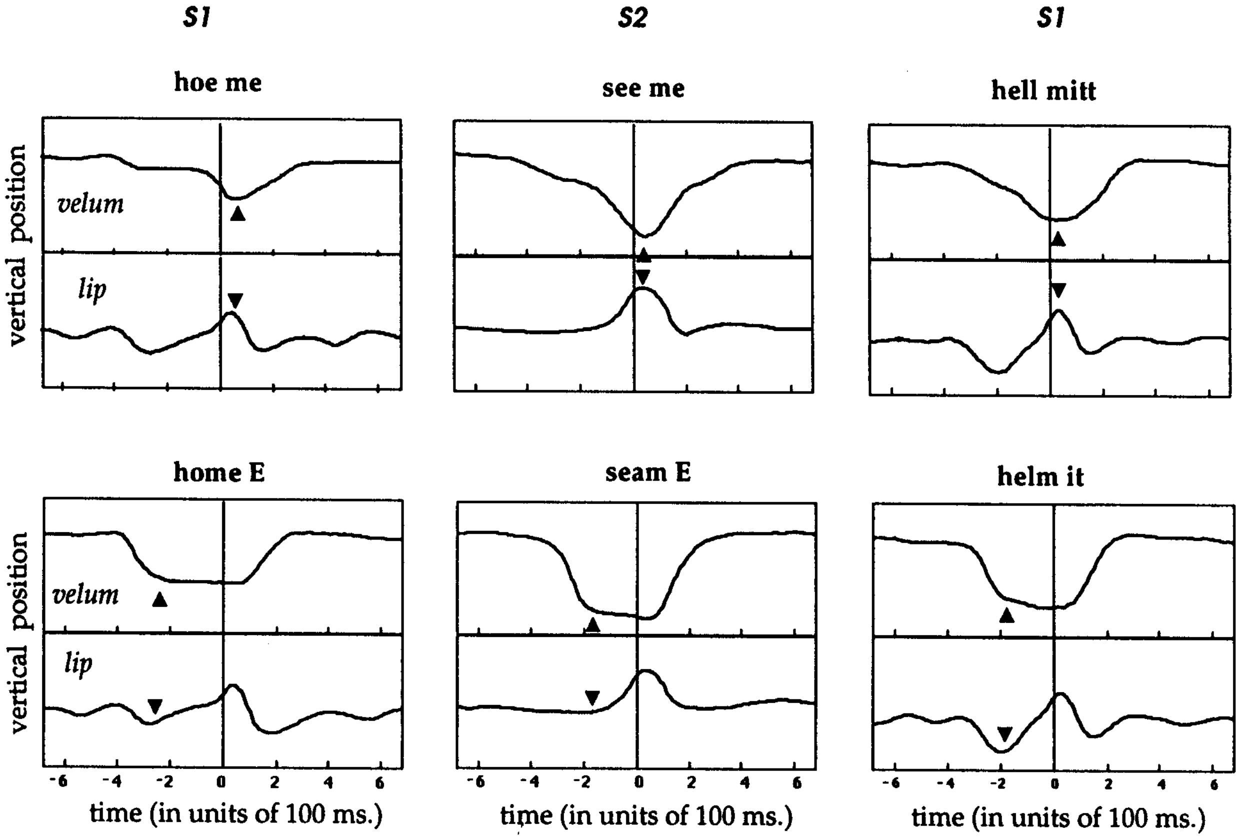

Figure 2. Sample velum and lower lip movements (in the form of ensemble averages) for sequences with word-initial (top panels) and word-final (bottom panels) nasal consonants from two subjects (S1 and S2). The vertical line in the middle of each panel marks the onset of bilabial contact for the /m/. The triangles in the panels mark velum lowering offset and the coordinated event in the lower lip movement.

ciated with word-initial nasals and the other with word-final nasals. That is, the achievement of the velic target cooccurred with completion of lip raising for initial nasals but with initiation of lip raising for final nasals. As a result of this difference, the vowel preceding the final nasal was associated with considerably lower velic height than the vowel preceding the initial nasal. This pattern is clearly consistent with phonological evidence that vowels before word-final nasals are more likely to be nasalized than are vowels before word-initial nasals.

To see whether the patterns described reflected syllable organization, word organization, or some combination, labio-velic movement patterns were compared for sequences having syllable-final nasals in word-medial and word-final positions. Figure 3 provides sample comparisons for the two subjects' productions of

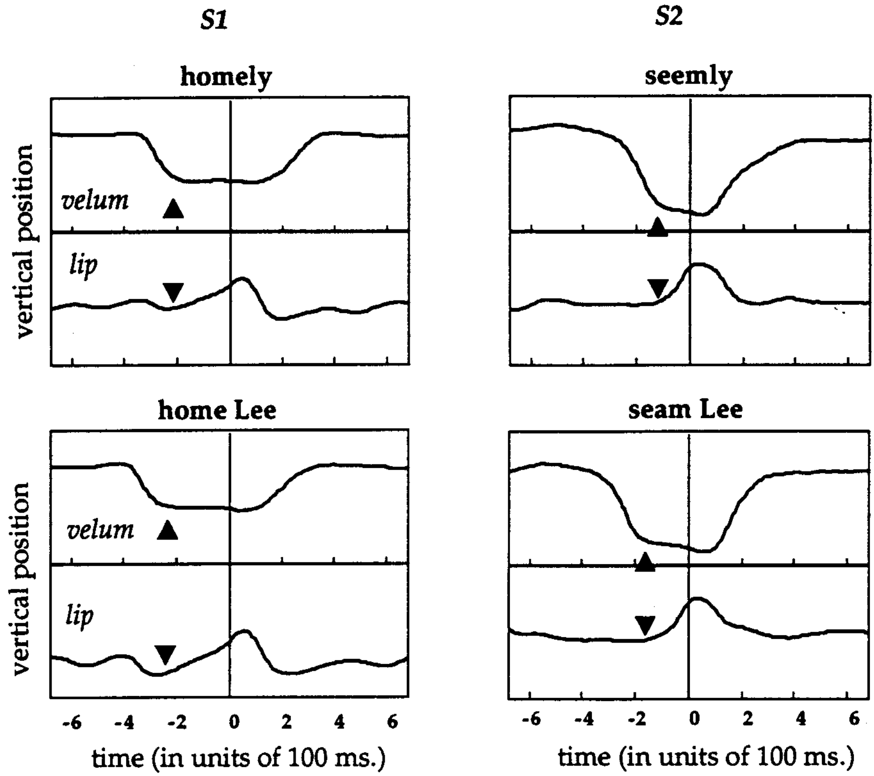

Figure 3. Sample velum and lower lip movements (in the form of ensemble averages) for sequences with syllable-final nasals in word-medial (top panels) and word-final (bottom panels) positions from S1 and S2. The vertical line in the middle of each panel marks the onset of bilabial contact for the /m/. The triangles in the panels mark velum lowering offset and the coordinated event in the lower lip movement.

home Lee versus *homely* and *seam Lee* versus *seemly.* The patterns bear a clear resemblance to those shown in Figure 2 for *home E* and *seam E.* A low velic plateau is evident in all sequences with syllable-final nasals, although the plateau is somewhat shorter for those nasals in word-medial position, reflecting the shorter vocalic duration of the first syllable of the bisyllabic single word than the first word of the matched bisyllabic two-word sequence. Nonetheless, velic lowering offset and lip raising onset continued to be temporally linked for syllable-final nasals, despite the change in word position. This inter-articulator pattern was therefore taken to be an indicator of the presence of a syllable-final nasal consonant.

Similarly, the pattern described for word-initial nasals was found to be syllable-based. The pair *pygmy/pig me* was used by Krakow (1989) to ensure a syllable break before the word-medial /m/ to contrast a word-medial syllable-initial nasal and a word-initial nasal. The sequence /gm/ is not, however, compatible with any alternative placement of the syllable boundary, limiting its use to this comparison alone. Velum lowering offset was timed to lip raising offset in both these sequences for the two subjects, consistent with the pattern described for the word-initial nasals above.

It is possible, therefore, to describe a bi-stable pattern of labio-velic coordination that distinguishes syllables with initial bilabial nasal consonants from those with final nasal consonants: the end of velum lowering aligns either with the beginning or the end of lip raising toward the position required for the bilabial nasal consonant.

The distinct patterns of labio-velic coordination observed for syllable-initial versus syllable-final nasals made it possible to compare the gestural patterns for word-medial nasals whose affiliation is unclear; i.e., phonotactic constraints do not decide between syllabification with the preceding vs. the following vowel (Figure 1, col. 1). It has been proposed that, in some instances, such a consonant might be "ambisyllabic," i.e., a member of both syllables. (For further discussion of ambisyllabicity, see Kahn, 1976; Selkirk, 1982.) However, the movement patterns for the sequences in column 1 indicated that the nasal consonant was typically affiliated with the preceding or the following vowel, but not simultaneously with both. In most cases, syllabification was determined by the stress pattern, with primary stressed syllables attracting the nasal consonant. Thus, for example, the nasal consonants in *seamy* and *homey* appeared to be syllable-final (velic lowering offset timed to lip raising onset), whereas the nasal consonant in *pomade* appeared to be syllable initial (velic lowering offset timed to lip raising offset), for both speakers. Figure 4 provides sample movement patterns showing stress-based syllabification of medial nasals.

The remaining two sequences of this type, *helmet* and *Seymour,* showed more variable patterning. The movement patterns of one subject (S1) showed syllable-final organization of the nasal consonant for both of these words, linking the nasal

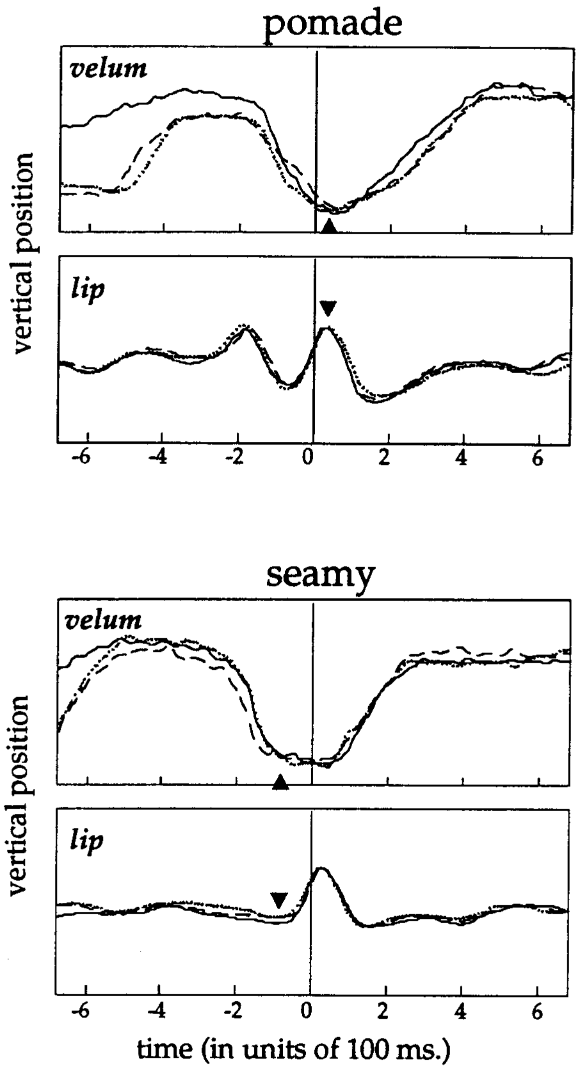

Figure 4. Sample velum and lower lip movements for sequences with word-medial intervocalic nasals, from S2. Three tokens are displayed in each panel with different line types. The vertical lines in the panels mark the onset of bilabial contact for the /m/. The triangles mark velum lowering offset and the coordinated event in the lower lip movement. The nasal consonant in *pomade* shows syllable-initial organization whereas the nasal consonant in *seamy* shows syllable-final organization.

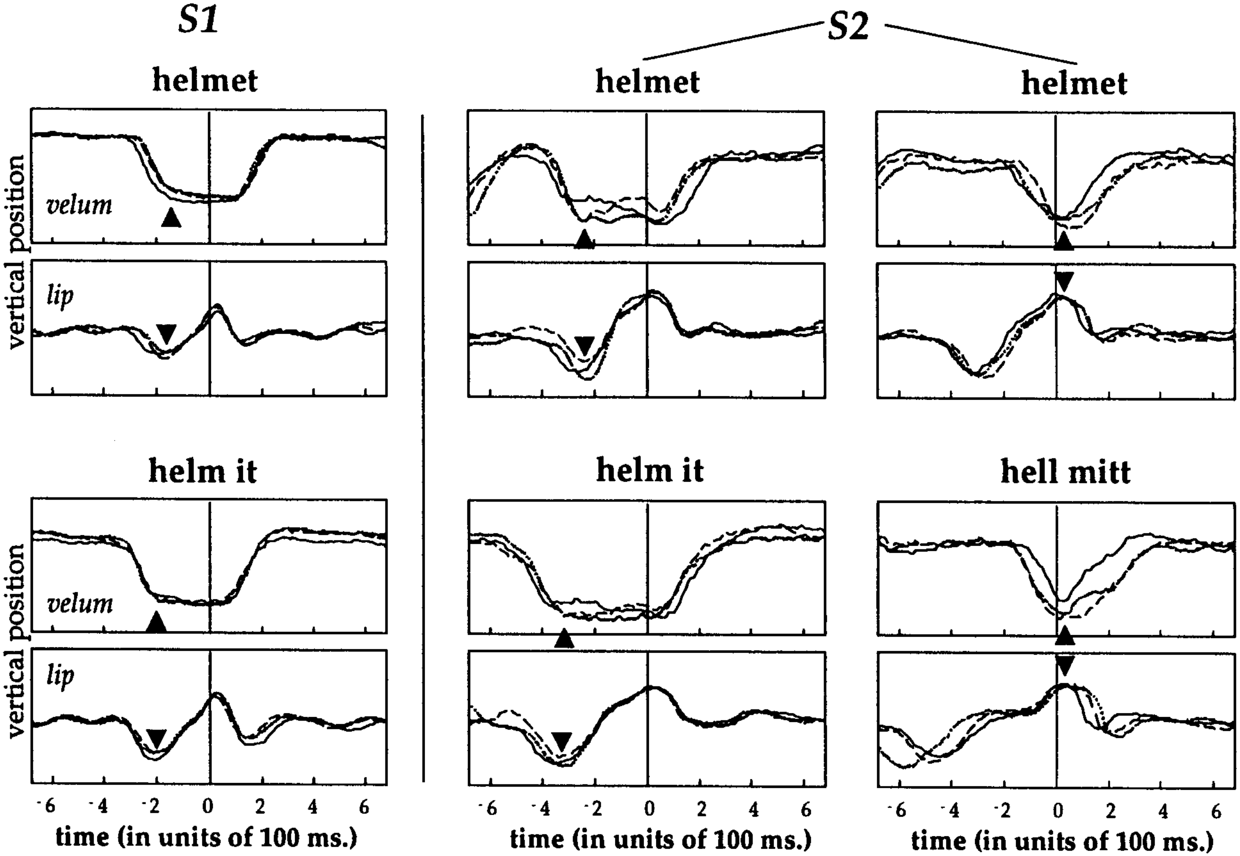

Figure 5. Labio-velic coordinative patterns for tokens of *helmet* (*top panels*) shown above tokens of *helm it* or *hell mitt,* depending upon whether the patterns for *helmet* resemble those for *helm it* or *hell mitt.* The vertical line in the middle of each panel marks the onset of bilabial contact for the /m/. The triangles mark velum lowering offset and the coordinated event in the lower lip movement. Three tokens are displayed in each panel. S1 had a consistent pattern, while S2 alternated between two patterns.

with the primary stressed syllable. However, the patterns of the second subject (S2) varied from token to token for these sequences. Some tokens of *helmet* showed syllable-final organization of the nasal consonant, and some showed syllable-initial organization (Figure 5). Similarly, some tokens of *Seymour* showed syllable-final, and some syllable-initial organization of the nasal consonant. Still other tokens of *Seymour* were hard to characterize as one or the other type.

It seems clear that the question of ambisyllabicity and of variation in the production of sequences of this sort requires a larger data set, with additional subjects, sequences, and tokens. However, some preliminary observations can be made. First, despite some evidence of variability in patterning, the vast majority of the tokens in this set (Figure 1, col. 1) were organized such that the nasal consonant appeared syllable-final or syllable-initial, but not a combination. And generally the nasal consonant affiliated with the syllable that received primary stress. Hence, these data provide little suppport for the notion of ambisyllabicity as a combination of syllable-initial and syllable-final attributes, but the data do suggest that some word-medial consonants are likely to show free variation with respect to syllable affiliation. Considering the two that varied here, i.e., the nasal consonants in *helmet* and *Seymour,* the following observations can be made: A speaker may affiliate a medial consonant with the upcoming syllable instead of the preceding syllable which bears primary stress (1) when the stressed syllable already contains a post-vocalic consonant, as in the case of *helmet,* or (2) when the following syllable receives secondary stress, as in the case of *Seymour.* Further study is necessary to determine, with greater certainty, the kinds of sequences that are likely to vary in this way.

Returning, however, to cases in which the nasal consonant is unambiguously syllabified (e.g., those in Figure 1, cols. 2–5), much stronger claims can be made. For such sequences, there are characteristic patterns of inter-articulator timing associated with bilabial nasal consonants in different syllable positions. A consistent pattern of bi-stability distinguished sequences with syllable-initial versus syllable-final nasals: the end of velic lowering coincided with the end of lip raising for the syllable-initial nasals (whether word-medial or -initial), but with the beginning of lip raising for the syllable-final nasals (whether word-medial or -final). These results strongly support the notion of the syllable as an articulatory unit and suggest as well that additional insight into the question of ambisyllabicity is likely to be found in speech production data.

3. SENTENCES

Recent work on velic movements shows that, in addition to the effects of a segment's position in a syllable, there are effects of a segment's position in larger domains—such as a phrase or sentence (the span of a breath group). Over the course of such domains, one observes an overall decline in peak velic position for obstruents (Bell-Berti & Krakow, 1991b; Krakow, Bell-Berti, & Wang, 1991). This pattern is similar to the declination of fundamental frequency over the course of a phrase or sentence, long noted in the phonetics literature (see Brekenridge, 1977; Cooper & Sorenson, 1981; Gelfer, 1987; Maeda, 1976). While F0 declination has been treated by some as resulting from intentional control of muscles affecting F0 (Breckenridge, 1977; Cooper & Sorenson, 1981), Gelfer's (1987) acoustic and physiological research shows that F0 declination, along with a concomitant decline in acoustic amplitude, is largely the passive consequence of declining subglottal pressure over the course of a sentence.

Recent findings of declination in measures of the jaw (Vatikiotis-Bateson & Fowler, 1988; Vayra & Fowler, 1992), the velum (Bell-Berti & Krakow, 1991b), and vowel formant-frequency patterns (reflecting tongue-jaw positions) (Vayra & Fowler, 1992) lend support to the notion that declination is a general phenomenon, with effects on laryngeal-respiratory and supralaryngeal events in the production of spoken sentences (Fowler, 1988). For example, kinematic data collected by Vatikiotis-Bateson and Fowler (1988) showed weak but consistent declination in the extent, peak velocity, and duration of jaw opening and closing gestures over the course of reiterant speech utterances. Vayra and Fowler (1992) examined measures of F1 and F2 for the vowels in isolated trisyllabic Italian pseudowords. The results showed that the vowels became more centralized from early to late: open vowels became less open (F1 decreased) and closed vowels became less closed (F1 increased), results consistent with increased relaxation or reduced energy later in the utterance. The F2 measures indicated that there was also centralization along the front-back dimension.

These results, along with informal observations of what appeared to be declination patterns in velic data collected for other purposes, prompted a systematic investigation of possible velic declination (Bell-Berti & Krakow, 1991b; Krakow, Bell-Berti, & Wang, 1991). The set of seven utterances constructed for the study, ranging in length from three to nine syllables, is listed in Figure 6. Each natural sequence was paired with a reiterant sequence consisting of the appropriate number of repetitions of the syllable *ten.* The natural sentence was produced first, followed by, and functioning as a model for, the reiterant version. The natural sequences were designed to minimize phonetic context effects on the velum (and still be meaningful); the reiterant sequences were designed to eliminate such effects entirely. Each of the subjects produced 12 randomized repetitions of each natural–reiterant sentence pair. Velum movement was monitored with the Velotrace and a modified Selspot system. Measurements were made of peak velic positions for each /t/ in the reiterant sentences and for the first and last /s/ in the natural sentences (i.e., the /s/ in *Sue* and the /s/ in *Sid*).

Figure 7 provides sample movement patterns for some of the reiterant sequences, showing that the velum is consistently lower at the last than at the first

NATURAL SENTENCES	REITERANT SENTENCES
Sue saw Sid.	Ten ten ten.
Suzy saw Sid.	Tenten ten ten.
Suzy saw sad Sid.	Tenten ten ten ten.
Suzy saw sexy Sid.	Tenten ten tenten ten.
Suzy saw sad sexy Sid.	Tenten ten ten tenten ten.
Suzy saw sexy sassy Sid.	Tenten ten tenten tenten ten.
Suzy saw sad sexy sassy Sid.	Tenten ten ten tenten tenten ten.

Figure 6. Stimuli for velum declination experiment.

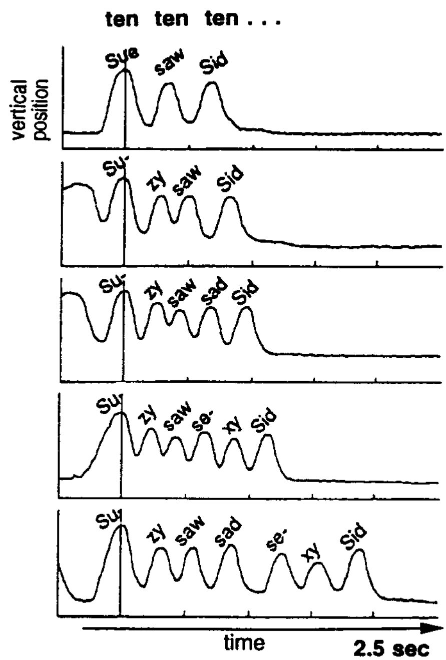

Figure 7. Sample velum movements for tokens of reiterant sentences of varying length from a subject in the declination study. The natural sentences that served as models appear above the movements for the reiterant sentences. Each peak in the movements is associated with a /t/ from one of the reiterant syllables.

peak of each sentence. A lower velic peak at the end than at the beginning of the sentences was observed for all sequence types (whether natural or reiterant, short or long) and for all subjects. A reduction in the height of velic peaks over the course of a sentence is consistent with a notion of decreasing energy over its time course, as higher velic positions are normally associated with increased activity of the levator palatini (see Bell-Berti, this volume, for a review of muscle activity in velopharyngeal function).[3] The patterns shown in Figure 7, however, indicate that while there was a general decline, there were also some local increases and decreases, similar to patterns observed for F0 and acoustic amplitude (Gelfer, 1987).

To determine the nature of such local effects on the velic movements, it was necessary to examine changes in velic measures in the middle of the utterances and to control for possible stress effects or effects of syllable position within a word. For this purpose, the reiterant syllables corresponding to the bisyllabic words (*Suzy, sexy,* and *sassy*) in the natural sequences were examined. Peak velic position was obtained for the reiterant syllables corresponding to the stressed and unstressed syllables in each bisyllabic word. In this way, it was possible to compare velic peaks for stressed syllables occurring earlier and later and for unstressed syllables occurring earlier and later. Comparisons were made in a pairwise fashion because some sentences had only two of the three bisyllabic words.

The mean peak velic positions in the reiterant syllables corresponding to the bisyllabic word pairs are plotted in the panels of Figure 8 for each subject. The measures were obtained only from those sentences which contained both members of a given comparison pair. The earlier word of the pair occurs at the left of each panel and the later word at the right. The following effects were observed. First, there was a consistent decline in peak velic position from earlier to later stressed syllables. Second, more often than not, unstressed syllables also showed a decline, but when present, it was always weaker than the decline in the stressed syllables. Stronger declination effects for stressed syllables were also reported by Vayra and Fowler (1992), based on their measures of jaw position and of F1 formant values for the vowel /ɑ/ produced by Italian speakers. Third, in all but two comparisons between earlier and later means, velic peaks were higher for stressed than for unstressed syllables. Whether these effects are attributable to stress or within-word declination, or to a combination of the two, is unclear because stressed syllables were always first syllables and unstressed syllables were always second syllables. However, there are data that indicate that stress probably played an important role in these velic patterns. For example, Vaissière (1988) showed that velic peaks for the oral consonants in CVN sequences were higher in stressed than in unstressed syllables—just the pattern that was observed in the velic declination data. There is also evidence to suggest that supralaryngeal declination is largely a phrasal rather than a word-level phenomenon. According to Vayra and Fowler (1992), declination patterns of the jaw and formant frequencies observed in isolated trisyllables are weakened or disappear when the trisyllables are embedded

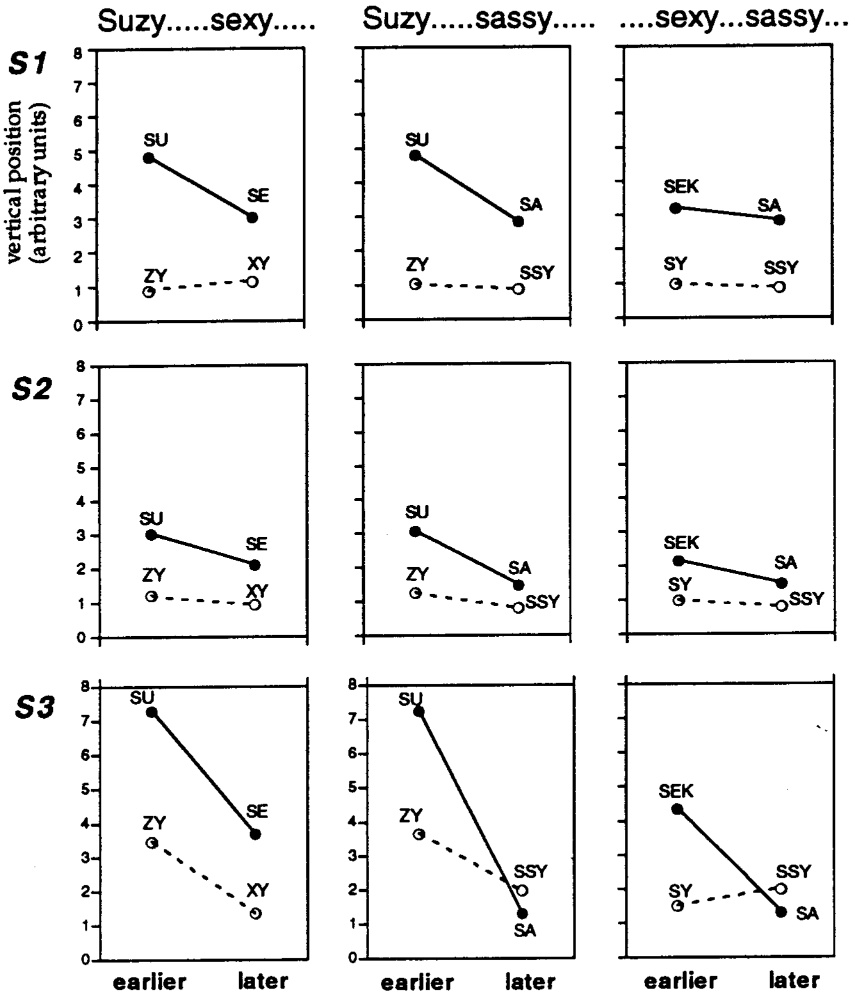

Figure 8. Means for peak velum position associated with the /t/ of the reiterant syllables in earlier and later positions in the sentences. "Earlier" and "later" measures are, respectively, at the left and right of each panel. Panels at the left compare peaks in reiterant versions of *Suzy* and *sexy*, those in the middle compare peaks in reiterant versions of *Suzy* and *sassy*, and those at the right compare peaks in reiterant versions of *sexy* and *sassy*. Measures of stressed syllables are represented with filled circles, measures of unstressed syllables with open circles. Data are shown for the three subjects.

in carrier phrases. Given Vayra and Fowler's results and those of Vaissière (1988), the present findings suggest that there is a reduction in the contrast between velic peaks in stressed and unstressed syllables as they occur later in a sentence.

In general, there is evidence of declination of velic height over the course of a sentence from the first to the last syllable of a sentence and also over the medial regions of a sentence, with local perturbations due to stress and possibly also to syllable position in a word. Taken together with the recent studies of formant frequency and jaw declination, the velic data provide support for the notion of declination as a more general phenomenon in speech production than was previously assumed. To date, declination patterns have been observed in respiratory-laryngeal behavior, in velic and mandibular movements, and in vowel formant frequencies. All are compatible with a notion of decreasing energy later in a sentence.

4. STRESS

The preceding section prompts the question of whether there are manifestations of stress on velic movement patterns, apart from the higher peaks observed for oral consonants in stressed syllables (Vaissière, 1988). In his cross-language survey of nasalization, Schourup (1973) reported a relation between stress and nasalization: stressed vowels appeared more likely than unstressed vowels to become nasalized by assimilation. Although very few experimental studies have addressed stress effects on the velum, the results appear to be generally consistent with Schourup's report. Vaissière's (1988) subjects showed not only higher velic peaks for oral consonants in stressed syllables, but also lower velic valleys for nasal consonants in the stressed syllables. And Krakow's (1987, 1989) subjects kept the velum lowered for a longer time in stressed than in unstressed syllables beginning or ending with a nasal consonant.

Schourup was also interested in the relation between vowel height and nasalization, noting like others before and after him (e.g., Beddor, 1982; Chen, 1975; Henderson, 1984; Lightner, 1970) that low vowels are more likely to become nasalized than high or mid vowels. Taking the vowel height patterns together with his observations on the effects of stress, Schourup concluded that stressed low vowels are particularly susceptible to contextual nasalization. This raises the question of whether velic movements for all vowels are similarly affected by stress, a question that has not been systematically addressed in any of the studies in the literature.

Vaissière's work shows that for consonants (at least for obstruents and nasals), adding stress enhances intrinsic velic positional differences: the high velic positions associated with obstruents become higher, whereas the low velic positions associated with nasal consonants become lower. Although vowels tend to have velic positions intermediate between those of obstruents and nasal consonants, high vowels have intrinsically higher velic positions than low vowels. The difference is so robust that it affects velic positions for adjacent obstruents or nasal consonants (Bell-Berti, Baer, Harris, & Niimi, 1981; Henderson, 1984). Thus it is possible that adding stress will merely enhance the intrinsic vocalic contrast by raising velic positions for high vowels but lowering them for low vowels.

To address this question, Velotrace data were collected as two subjects produced 12 tokens of the sequences /mɑ́bɑb/, /mɑbɑ́b/, /míbɑb/, /mibɑ́b/, /bɑ́bɑm/, /bɑbɑ́m/, /bɑ́bim/, /bɑbím/ in a brief carrier phrase. This set of sequences provided comparisons between velic positions for stressed and unstressed /i/ and /ɑ/ following an initial nasal and preceding a final nasal. Positional measures, designed to span the duration of each vowel adjacent to a nasal consonant, were obtained for a number of acoustically based reference points: for words with initial nasal consonants, velic height was measured at first vowel onset, midpoint, and offset; for words with final nasals, velic height was measured at second vowel onset, midpoint, and offset.

The results for syllables with initial nasals are shown in Figure 9, which displays, for each subject, the velic height measures obtained for the three measurement points averaged over the 12 tokens of each sequence. Intrinsic differences in velic height between /ɑ/ and /i/ were evident for both subjects in stressed and unstressed syllables: the velum was lower for /ɑ/ than for /i/ at all corresponding measurement positions. For S1, stress enhanced these intrinsic differences: In syllables beginning with a nasal consonant, the velum was higher for /i/ when stressed than when unstressed, but lower for /ɑ/ when stressed than when unstressed, for most of the vowel's duration. For S2, however, the velum was lower for both stressed /ɑ/'s and stressed /i/'s following the initial nasal than for unstressed /ɑ/'s and /i/'s, respectively.

Figure 10 shows the corresponding data for vowels preceding final nasals in /bɑm/ and /bim/. Again, it can be seen that there were intrinsic differences in velic height between the two vowels, with lower positions for /ɑ/ than for /i/; for these sequences, the differences were evident at the vowel midpoint and offset for both subjects. And, as with the vowels following a nasal consonant, stress effects on vowels preceding a nasal consonant were different for the two subjects. For S1, the velum was higher for stressed than for unstressed /i/, but lower for stressed than for unstressed /ɑ/. For S2, however, the velum was lower in stressed than in unstressed syllables for both /ɑ/ and /i/.

Clearly, the two subjects used two different strategies for stressing syllables, at least with respect to velic movements. For one subject, stress enhanced the already existing contrast between the high and low vowels by increasing velic height in the former case and decreasing height in the latter. For the other subject, stress resulted in a lower velum, regardless of vowel height. Similar variability in the

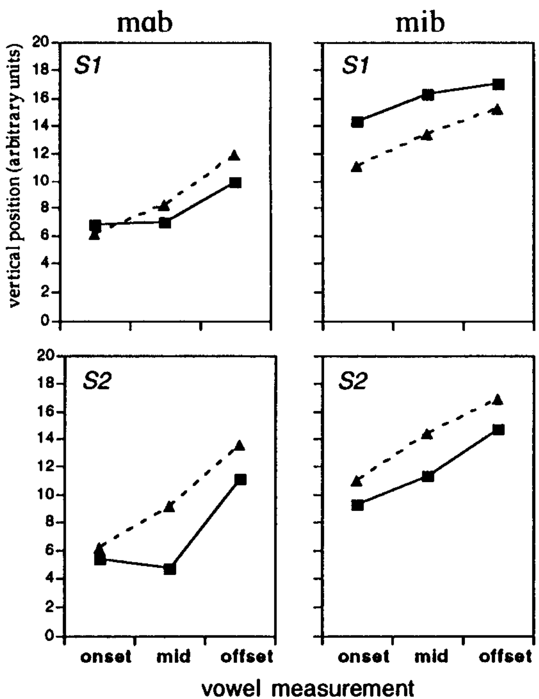

Figure 9. Mean velum position at the onset, the middle, and the offset of stressed (squares) and unstressed (triangles) vowels following an initial nasal consonant. The vowels /ɑ/ and /i/ are represented in the left and right panels, respectively. Data are shown for the two subjects.

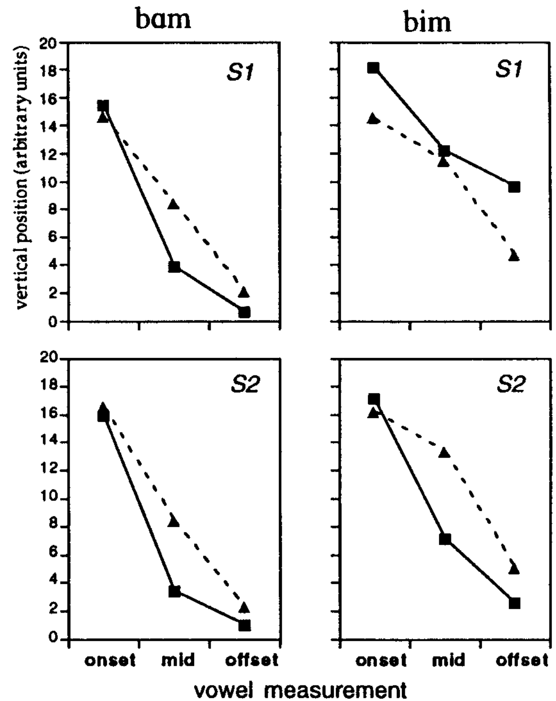

Figure 10. Mean velum position at the onset, the middle, and the offset of stressed (squares) and unstressed (triangles) vowels preceding a final nasal consonant. The vowels /ɑ/ and /i/ are represented in the left and right panels, respectively. Data are shown for the two subjects.

effects of stress has been found for the tongue. For example, Kent and Netsell (1971) found that stress enhanced the intrinsic differences in tongue position for different segments for their two speakers. That is, /i/ had a higher-fronter tongue position and /æ/ had a lower-fronter tongue position when stressed than when unstressed. These data parallel the present findings for S1. In contrast, Houde (1967) reported that for his speaker the tongue positions for high and low vowels (/i/, /u/, /ɑ/) were consistently lower in stressed than in unstressed syllables. These data parallel the current findings for S2. It would be interesting to know whether the two subjects whose velic movements were examined here and showed differing effects of stress would show parallel differences in their tongue movements.

As for Schourup's claim that stress increases the likelihood of assimilatory nasalization on vowels, the present data suggest that this may not hold for both high and low vowels for all speakers. However, a more specific claim of Schourup that vowels most likely to be contextually nasalized are low, stressed, and precede a final nasal consonant does find support in these data. For both subjects in this study, the velum was lowest for stressed /ɑ/'s preceding a final nasal consonant (cf. Figures 9 and 10).

5. SPEAKING RATE

Another nonsegmental variable affecting velic movement patterns is speaking rate. Studies of the velum (Bell-Berti & Krakow, 1991a; Moll & Shriner, 1967), like those of other articulators (cf. Browman & Goldstein, 1991; Hardcastle, 1985; Munhall & Löfqvist, 1992; Saltzman & Munhall, 1989), indicate that as the rate increases, there is greater overlap among articulatory gestures for adjacent and near-adjacent segments. For example, Bell-Berti and Krakow (1991a) showed that, at a speaker's self-selected normal rate, the velic movement pattern for a sequence like "It'***s a lan***sal again" contains a small lowering movement from the peak for the obstruent /s/ of /ɪts/ toward a somewhat lower position for the /əlɑ/ sequence, followed by a more extreme lowering movement for the nasal consonant. At a rapid rate, however, the small movement for the vocalic portion (including the /l/, which behaves much like a vowel in intrinsic velic positioning) is usually overlapped with, and visually indistinguishable from, the large movement for the nasal consonant (Figure 11a). That the vocalic portion is associated with a small lowering gesture underlyingly is supported not only by the normal rate data but also by corresponding minimal contrasts containing no nasal consonant, at the normal and rapid speaking rates (Figure 11b). Thus the evidence supports the view that an increase in speaking rate is associated with greater overlap of gestures for adjacent (and near-adjacent) segments. Furthermore, cross-speaker comparisons showed a relation between speaking rate and extent of overlap. That is, the speaker

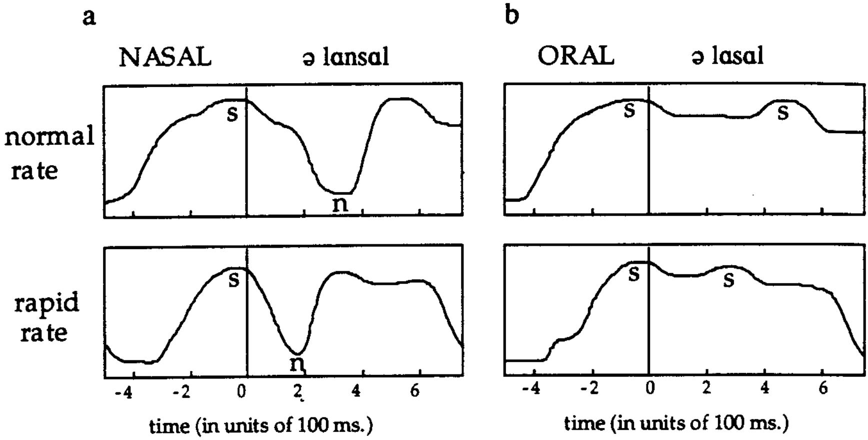

Figure 11. (a) Sample velum movements for tokens of *It's a lansal again*, showing two-stage lowering between the /s/ of *It's* and the /n/ of *lansal* at a normal speaking rate (top panel) and single-stage lowering at a rapid rate (bottom panel). The vertical line in the middle of each panel marks the release of the /s/ of *It's*, as determined from the acoustic waveform. (b) Sample velic movements for tokens of *It's a lasal again*, showing velic lowering for the vocalic sequence following the /s/ of *It's* at both normal and rapid speaking rates. The velum rises again for the /s/ of /ləsal/ at both rates. The vertical line in the middle of each panel marks the release of the /s/ of *It's*, as determined from the acoustic waveform. (The same speaker is represented in both parts.)

with the fastest self-selected "normal" rate in Bell-Berti and Krakow (1991a) produced most utterances with single-stage velic lowering (overlapping vocalic and nasal consonantal gestures), whereas the speaker with the slowest "normal" rate produced many more utterances in which two or more stages of lowering were evident.

Other studies on the effects of speaking rate show a reduction in the magnitude of velic movements at faster rates (e.g., Kent et al., 1974; Kuehn, 1976). Both types of observation (i.e., a decrease in multistage gestures and a reduction in positional extremes) are predicted by the coproduction model, as both are outcomes of increased temporal overlap of gestures, although no single study has looked for both in the same data. A reanalysis of the sequences with nasal consonants examined in Bell-Berti and Krakow (1991a), and listed in Figure 12, supports the claim that the two types of observation are related effects of increasing gestural overlap. The position of the velum at the release of the /s/ of *It's* or *It's say* was measured for each sequence containing a nasal consonant in that study (Figure 13). The results show that the velic peak was consistently higher in the normal than in the fast rate productions, indicating that there was less overlap between the gesture for the nasal consonant /n/ and that for the obstruent /s/ at the normal than at the fast rate. In addition, the velic peak was higher when more

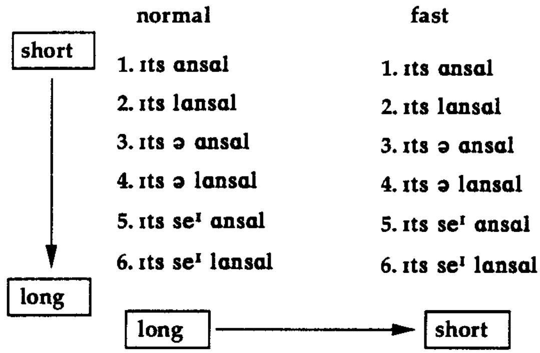

Figure 12. Stimuli for rate experiment.

vocalic segments intervened between the /s/ and the /n/, as shown in Figure 13. That is, increasing the duration of the vocalic string by slowing the rate or by adding segments, one obtains a larger separation between the extreme (opposite) positional requirements of the /s/ and the /n/. The same manipulations have been shown by Bell-Berti and Krakow (1991a) to increase the likelihood that separate vocalic and nasal consonantal lowering movements will be seen (Figure 14).

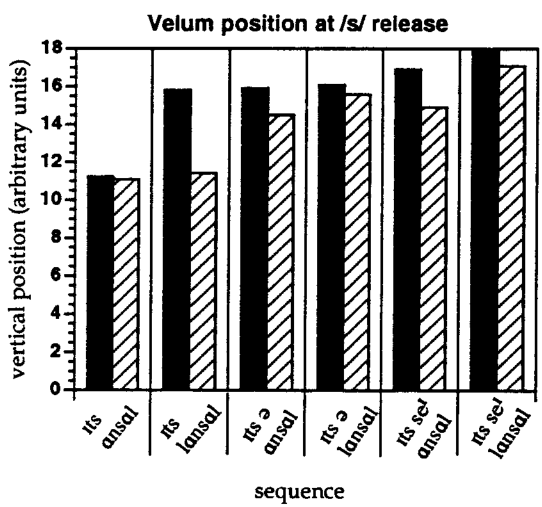

Figure 13. Mean velum position at the release of the /s/ of *It's* or *It's say* obtained from 12 tokens of each of the sequences shown along the x-axis at each of two speaking rates. Normal rate sequences are represented with solid bars, rapid rate sequences with striped bars. (The same speaker is represented here as in Figure 11.)

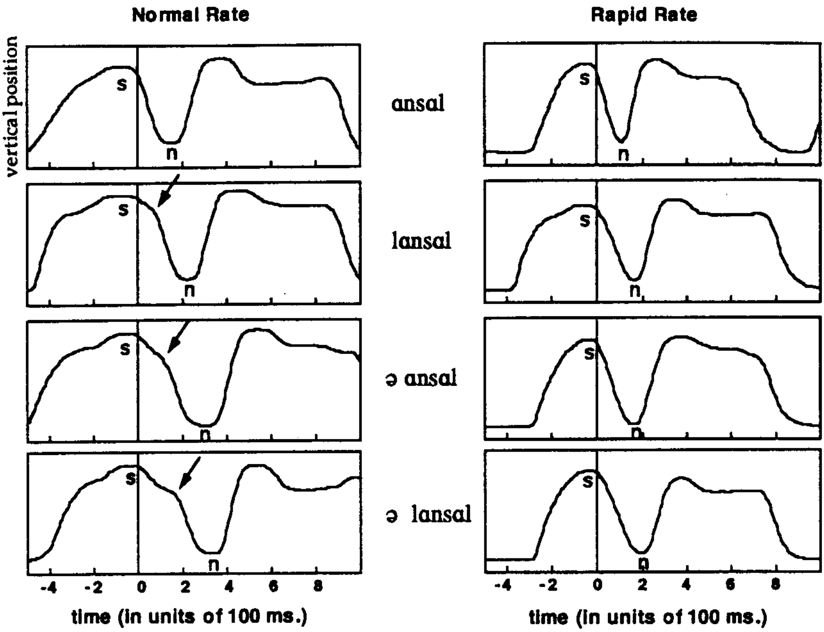

Figure 14. Sample velum movements for sequences produced at normal (left panels) and rapid (right panels) rates. The number of segments intervening between the /s/ of *It's* or *It's say* and the following /n/ increases from the top to the bottom panels of the figure. The arrows mark the emergence of a second stage of velic lowering.

The effects of rate manipulations on velic positional extremes have also been addressed in studies by Kent et al. (1974) and Kuehn (1976). Both these studies suggest that subjects may vary in the manner in which they implement a rate change and lead to the conclusion that speaker-related differences are so robust and interesting that additional larger scale studies of this issue are called for. For example, Kent et al. reported that both subjects in their study reduced the time taken to produce the sentence *Soon the snow began to melt* by about half when they switched from a moderate, conversational rate to a maximum, rapid rate (Figure 15). Although both also maintained the relative timing of velic peaks and valleys, the rate change was accomplished in different ways by the two speakers: One speaker (S1) increased the velocity of his faster utterances considerably, and showed a minimal change in movement extent. The other speaker (S2) showed little change in the velocity of his movements but a considerable reduction in the movement extremes. Since the time taken to produce a sentence may be reduced by an increase in the velocity of movement, a decrease in movement extent, or by some combination of these changes, speakers may vary in their strategy. Similar

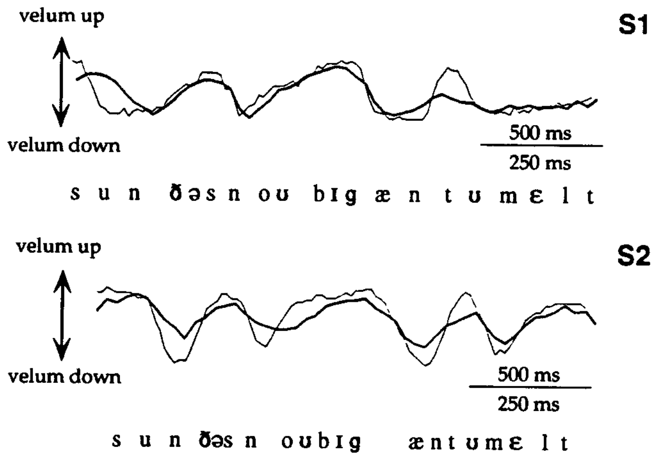

Figure 15. Vertical velum movement patterns obtained from a cinefluorographic study as two subjects produced *Soon the snow began to melt* at moderate (thin lines) and rapid (thick lines) speaking rates. The rapid movements, which took about half the time of the normal rate movements, are time-normalized and overlaid on the normal rate movements. Two time scales are provided. Adapted from Kent et al. (1974) with permission.

differences among subjects are reported in studies of the effects of rate changes on lip and tongue movements (see, for example, Kuehn & Moll, 1976). Perhaps some speakers (or some speakers in particular situations) feel more constrained to maintain or approximate positional extremes than others; such speakers may be concerned with the effects of the rate change on intelligibility.

Another speaker-to-speaker difference in how rate affects velic movements was reported by Kuehn (1976), who showed that a reduction of postional extremes at rapid rates might, for some speakers, be observed only at the peaks *or* the valleys. The two subjects in Kuehn's study showed reduced range and duration of velic movement in rapid utterances that required opposite extreme velic positions in succession (e.g., VCNV or VNCV sequences). One subject (S1) reduced the range of movement by producing less extreme high positions (leaving low positions unaffected), whereas the other subject (S2) reduced the range by producing less extreme low positions (leaving high positions unaffected) (Figure 16).

Kuehn's account of the difference between the two subjects suggests that it is important to bear in mind that different speakers might use a different part of the total range of velic movement available at their normal rates. That is, Kuehn had noted that the speaker (S1) who reduced peak velic height in the faster condition had, at the normal rate, raised the velum beyond the level necessary to obtain sufficient velopharyngeal closure; the other speaker (S2) raised the velum just

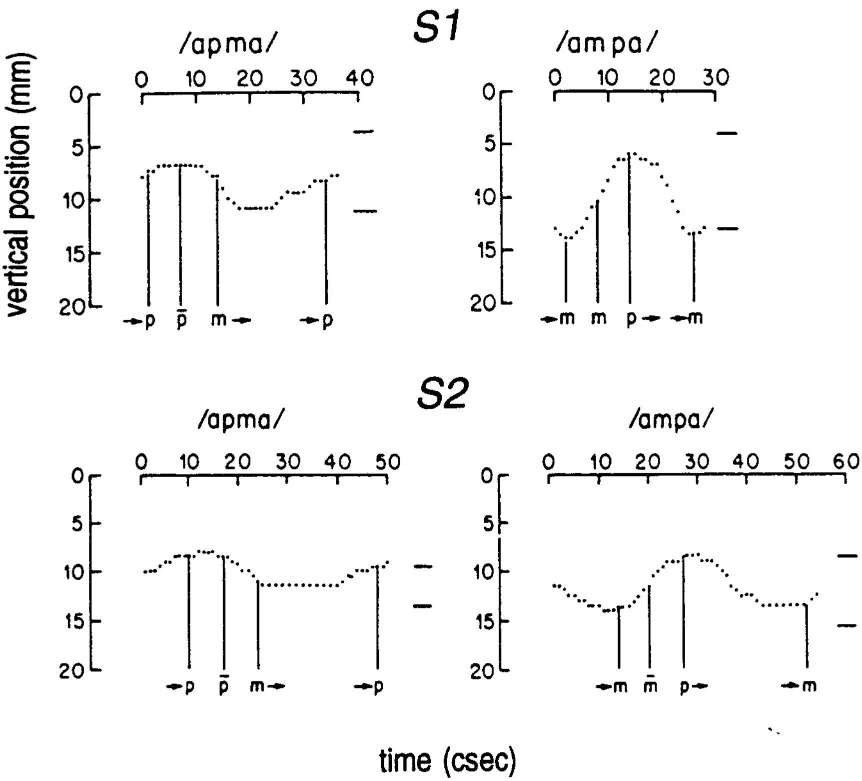

Figure 16. Vertical velum movement patterns obtained from a cinefluorographic study for two utterances (/ɑpmɑ/ and /ɑmpɑ/) produced by two subjects at a rapid speaking rate. The horizontal lines at the right of each graph mark the vertical range of velic displacement during the same sequences produced at a normal rate. Adapted from Kuehn (1976) with permission.

high enough to achieve adequate closure of the port at his normal rate. Hence, Kuehn's point is that, when asked to speak more quickly, S1 had raising to spare (so to speak), whereas S2 did not. For S2, the high peak could not be reduced without undesired acoustic consequences.

The studies done to date on velic movements at different speaking rates indicate that speakers may vary in the extent to which their fast productions approximate the extreme positions of their normal rate productions, since a rate change may be achieved by increasing the velocity and/or decreasing the range of movement. And, when a movement reduction occurs, it may affect both extremes of the normal range of movement, or just one.

6. DISCUSSION

Recent research has helped to elucidate the segmental organization of velic gestures and to highlight the fact that differences between oral and nasal consonants are only one aspect of this organization; that is, there are also differences related to vowel height and to consonant place, manner, and voicing (see Bell-Berti, this volume, for a review). Furthermore, the research described in this chapter shows that, in addition to such segmental influences, there are influences of syllable organization, syllable position in a sentence, stress, and speaking rate.

Each of these nonsegmental influences was examined here in turn, but it was possible to see that velic movement patterns are affected simultaneously by a variety of segmental and nonsegmental influences. For example, the sequences examined in the section on stress (NV́C, NVC, CV́N, CVN) showed the combined effects of stress, nasal consonant position, and vowel height. The highest velic positions were found in /i/ following initial nasals—stressed /i/ for S1, but unstressed /i/ for S2. The lowest velic peaks for both subjects were found in stressed /ɑ/ preceding final nasals. Despite subject-based differences in how stress affected velic height for /i/, the two subjects systematically distinguished the two vowels (/ɑ/ vs. /i/) in stressed versus unstressed syllables in the contexts of initial versus final nasal consonants.

Similarly, the declination data showed the overlapping effects of word stress and syllable position within a sentence. That is, although there was a general decline in the height of velic peaks over the course of a sentence, the decline was greater for stressed than for unstressed syllables. In most cases, stressed syllables were charecterized by higher velic peaks (for /t/) than unstressed syllables, but the greater decline in the stressed peaks meant that the contrast between stressed and unstressed syllables was reduced in later sentence positions. It can also be assumed that there are constraints on declination that are segment-related. That is, reduction in the peak positions for /t/ over the course of a sentence must have limits: a certain minimum height is required to produce an obstruent.

Thus, identification of different nonsegmental influences on velic movements makes it possible to consider how the different segmental and nonsegmental influences combine to shape the movement patterns. However, a larger scope of investigation is still necessary because the relation between velic activity and the activities of other articulators must also be considered. As described in the sections on stress, declination, and speaking rate, it is important to note that certain patterns of velum movement have parallels in the patterns of other articulators. Such patterns may reflect general characteristics of the speech production mechanism. For example, the declination pattern observed in velic positions over the course of a sentence adds to a growing body of literature showing that a reduction in energy at later positions in a sentence occurs in laryngeal-respiratory behavior (from measures of F0, acoustic amplitude, and subglottal pressure) and in the activities of the articulators (from measures of the jaw, the velum, and vowel formant frequencies). Another example of a general pattern was found in the section on stress. That is, one subject increased the height of the velum for stressed /i/'s as compared to unstressed /i/'s, but decreased the height of the velum for stressed /ɑ/'s as compared to unstressed /ɑ/'s. This subject enhanced the intrinsic differences in velic height between the high and low vowels. The other subject, however, consistently lowered the velum in stressed syllables relative to the corresponding unstressed syllables, regardless of vowel height. It was noted that similar cross-speaker differences have been reported for tongue movements. Some speakers use higher positions for stressed than unstressed /i/, but lower positions for stressed than unstressed /ɑ/. These speakers are enhancing the intrinsic contrast between the tongue positions for high and low vowels. Other speakers use lower tongue positions for stressed vowels, regardless of height.

In addition to examining the combined effects of different segmental and nonsegmental influences on the velum and to finding parallel patterns across articulators, it is also crucial to investigate those patterns which are specified by the coordination among articulators. For example, the coordination of velum lowering offset to the lip raising movement for a bilabial nasal consonant distinguished syllables with initial nasal consonants from those with final nasal consonants—across subjects, sequences, and tokens, regardless of whether the nasal consonants were at the middle or at the margins of a word. For syllable-initial bilabial nasals, the achievement of the low velum target and the high lower lip target coincided. For syllable-final bilabial nasals, however, the achievement of the low velum target was timed to the beginning of lower lip raising toward its target position.

This article, coupled with the article by Bell-Berti (this volume), shows how much has been learned about velic movement patterns in recent years. In contrast to earlier views of the velum as a functionally simple articulator, it is clear today that a variety of segmental and nonsegmental influences interact to shape velic movements. An understanding of these influences is critical to our understanding of the nature of speech motor organization and of the relation between speech motor organization and language sound structure.

ACKNOWLEDGMENTS

The research reported in this article was supported by NIH grants DC-00121 and HD-01994 to Haskins Laboratories. I thank Ignatius Mattingly, Fredericka Bell-Berti, and Catherine Browman for comments on an earlier draft of the article and for many stimulating discussions on speech motor organization and the role of the velum.

NOTES

[1] The location of primary stress in these utterances was based on its fixed location in the single-syllable words of each set (i.e., each row in the figure). The location of primary stress in the two-word items was matched to the one-word item in the same set. Thus, for example, because *homey* and *homely* have primary stress on the first syllable, so did *hoe me, home E,* and *home Lee* in this experiment. Since most of the items had primary stress on the first of the two syllables, a second set of utterances was constructed in Krakow (1989) to balance the position of stress. The results confirmed the findings of a bi-stable gestural organization for the syllable-initial vs. syllable-final nasals that is reported here, despite the presence of stress effects on other aspects of the movement.

[2] Lip contact data during /m/ were obtained with the use of an Electrolabiograph, a modified Electro-Glottograph, which supplied contact information on the lips rather than the vocal cords. (For additional information, see Krakow, 1989).

[3] This velic declination study was limited to measures of peaks for obstruents. However, additional measures, including peak-to-valley displacements, ought to be examined in future studies. Such measures should shed light on whether there is centralization of both peaks and valleys in later sentence positions or whether there is some other pattern.

REFERENCES

Beddor, P. S. (1982). *Phonological and Phonetic Effects of Nasalization on Vowel Height.* Unpublished doctoral dissertation. University of Minnesota, Minneapolis. (Reproduced by the Indiana University Linguistics Club, 1983).

Bell-Berti, F. (1980). Velopharyngeal function: A spatial-temporal model. In Lass, N. J. (Ed.), *Speech and Language: Advances in Basic Research and Practice* (Vol. 4, pp. 291–315). New York: Academic Press.

Bell-Berti, F., Baer, T., Harris, K., & Niimi, S. (1979). Coarticulatory effects of vowel quality on velar function. *Phonetica, 36,* 187–193.

Bell-Berti, F., & Harris, K. S. (1981). A temporal model of speech production. *Phonetica, 38,* 9–20.

Bell-Berti, F., & Hirose, H. (1975). Palatal activity in voicing distinctions: A simultaneous fiberoptic and electromyographic study. *Journal of Phonetics, 3,* 69–74.

Bell-Berti, F., & Krakow, R. A. (1991a). Anticipatory velar lowering: A coproduction account. *Journal of the Acoustical Society of America, 90,* 112–123.

Bell-Berti, F., & Krakow, R. A. (1991b). Velar height and sentence length: Declination? *Journal of the Acoustical Society of America, 89,* 1916 (At).

Benguerel, A.-P., Hirose, H., Sawashima, M., & Ushijima, T. (1977). Velar coarticulation in French: A fiberoptic study. *Journal of Phonetics, 5,* 149–158.

Bladon, R. W. A., & Al-Bamerni, A. (1982). One-stage and two-stage temporal patterns of velar coarticulation. *Journal of the Acoustical Society of America, 72,* S104 (At).

Boyce, S. E. (1988). *The Influence of Phonological Structure on Articulatory Organization* *in Turkish and in English: Vowel Harmony and Coarticulation.* Unpublished doctoral dissertation, Yale University, New Haven, CT.

Breckinridge, J. (1977). *Declination as a Phonological Process.* Murray Hill, NJ: Bell System Technical Memorandum.

Browman, C. P., & Goldstein, L. M. (1986). Towards an articulatory phonology. *Phonology Yearbook, 3,* 219–252.

Browman, C. P., & Goldstein, L. M. (1988). Some notes on syllable structure in articulatory phonology. *Phonetica, 45,* 140–155.

Browman, C. P., & Goldstein, L. M. (1991). Tiers in articulatory phonology, with some implications for casual speech. In J. Kingston and M. E. Beckman (Eds.), *Papers in Laboratory Phonology I: Between the Grammar and the Physics of Speech* (pp. 341–376). Cambridge: Cambridge University Press.

Chen, M. (1975). An areal study of nasalization in Chinese. In C. Ferguson, L. Hyman, & J. Ohala (Eds.), *Nasálfest: Papers from a Symposium on Nasals and Nasalization* (pp. 81–124). Stanford, CA: Stanford University, Department of Linguistics.

Clumeck, H. (1976). Patterns of soft palate movements. *Journal of Phonetics, 4,* 337–351.

Cooper, W. E., & Sorenson, J. M. (1981). *Fundamental Frequency in Sentence Production.* New York: Springer-Verlag.

Daniloff, R. G., & Moll, K. L. (1968). Coarticulation of lip rounding. *Journal of Speech and Hearing Research, 11,* 707–721.

Draper, M. H., Ladefoged, P., & Whitteridge, D. (1960). Expiratory pressures during speech. *British Medical Journal, 1,* 1837–1843.

Fowler, C. A. (1980). Coarticulation and theories of extrinsic timing. *Journal of Phonetics, 8,* 113–133.

Fowler, C. A. (1988). Periodic dwindling of acoustic and articulatory variables in speech production. *PAW Review, 3,* 10–13.

Fujimura, O. (1990). Methods and goals of speech production research. *Language and Speech, 33,* 195–258.

Fujimura, O., Miller, J. E., & Kiritani, S. (1975). An X-ray observation of movements of the velum and tongue. *Journal of the Acoustical Society of America, 58,* S40 (At).

Fujimura, O., Miller, J. E., & Kiritani, S. (1977). *A Computer-controlled X-ray Microbeam Study of Articulatory Characteristics of Nasal Consonants in English and Japanese.* Paper presented at the 9th International Congress on Acoustics, Madrid, Spain.

Gelfer, C. E. (1987). *A Simultaneous Physiological and Acoustic Study of Fundamental Frequency Declination.* Unpublished doctoral dissertation, City University of New York.

Hardcastle, W. J. (1985). Some phonetic and syntactic constraints on lingual coarticulation during /kl/ sequences. *Speech Communication, 4,* 247–263.

Henderson, J. B. (1984). *Velopharyngeal Function in Oral and Nasal Vowels: A Cross-Language Study.* Unpublished doctoral dissertation, University of Connecticut, Storrs.

Horiguchi, S., & Bell-Berti, F. (1987). The Velotrace: A device for monitoring velar position. *Cleft Palate Journal, 24,* 104–111.

Houde, R. A. (1967). *A Study of Tongue Body Movement During Selected Speech Sounds.* Unpublished doctoral dissertation, University of Michigan, Ann Arbor.

Kahn, D. (1976). *Syllable-based Generalizations in English Phonology.* Bloomington: Indiana University Linguistics Club.

Kent, R. D., Carney, P. J., & Severeid, L. R. (1974). Velar movement and timing: evaluation of a model of binary control. *Journal of Speech and Hearing Research, 17,* 470–488.

Kent, R. D., & Minifie, F. D. (1977). Coarticulation in recent speech production models. *Journal of Phonetics, 5,* 115–133.

Kent, R. D., & Netsell, R. (1971). The effects of stress contrasts in certain articulatory parameters. *Phonetica, 24,* 23–44.

Kozhevnikov, V. & Chistovich, L. (1965). *Speech: Articulation and Perception* (Trans. from Russian). Washington, DC: Joint Publications Research Service.

Krakow, R. A. (1987). *Stress Effects on the Articulation and Coarticulation of Labial and Velic Gestures.* Paper presented at the meeting of the American Speech-Language-Hearing Association, New Orleans, LA.

Krakow, R. A. (1989). *The Articulatory Organization of Syllables: A Kinematic Analysis of Labial and Velar Gestures.* Unpublished doctoral dissertation, Yale University, New Haven, CT.

Krakow, R. A., Bell-Berti, F., & Wang, Q. (1991). Supralaryngeal patterns of declination: Labial and velar kinematics. *Journal of the Acoustical Society of America, 90,* 2343 (At).

Kuehn, D. P. (1976). A cineradiographic investigation of velar movement in two normals. *Cleft Palate Journal, 13,* 88–103.

Kuehn, D. P., & Moll, K. L. (1976). A cineradiographic study of VC and CV articulatory velocities. *Journal of Phonetics, 4,* 303–320.

Lightner, T. M. (1970). Why and how does nasaliation take place? *Papers in Linguistics, 2,* 179–226.

Macchi, M. (1988). Labial articulation patterns associated with segmental features and syllable structure in English. *Phonetica, 45,* 109–121.

Maeda, S. (1976). *A Characterization of American English Intonation.* Unpublished doctoral dissertation, Massachusetts Institute of Technology, Cambridge.

Matisoff, J. A. (1975). Rhinoglottophilia: The mysterious connection between nasality and glottality. In C. Ferguson, L. Hyman, & J. Ohala (Eds.), *Nasálfest: Papers from a Symposium on Nasals and Nasalizaztion* (pp. 317–331). Stanford, CA: Stanford University, Linguistics Department.

Moll, K. L. (1965). A cinefluorographic study of velopharyngeal function during various activities. *Cleft Palate Journal, 2,* 112–122.

Moll, K. L., & Daniloff, R. G. (1971). Investigation of the timing of velar movements during speech. *Journal of the Acoustical Society of America, 50,* 678–684.

Moll, K. L., & Shriner, T. H. (1967). Preliminary investigation of a new concept of velar activity during speech. *Cleft Palate Journal, 4,* 58–69.

Munhall, K., & Löfqvist, A. (1992). Gestural aggregation in speech: Laryngeal gestures. *Journal of Phonetics, 20,* 111–126.

Nittrouer, S., Munhall, K., Kelso, J. A. S., Tuller, B., & Harris, K. (1988). Patterns of interarticulator phasing and their relation to linguistic structure. *Journal of the Acoustical Society of America, 84,* 1653–1662.

Ohala, J. J. (1971). Monitoring soft palate movements in speech. *Project in Linguistic Analysis, 13,* J01–J015.

Ohala, J. J. (1975). Phonetic explanations for nasal sound patterns. In C. Ferguson, L. Hyman, & J. Ohala (Eds.), *Nasálfest: Papers from a Symposium on Nasals and Nasalization* (pp. 289–315). Stanford, CA: Stanford University, Linguistics Department.

Ohala, M. (1975). Nasals and nasalization in Hindi. In C. Ferguson, L. Hyman, & J. Ohala (Eds.), *Nasálfest: Papers from a Symposium on Nasals and Nasalization* (pp. 317–331). Stanford, CA: Stanford University, Linguistics Department.

Öhman, S. E. G. (1966). Coarticulation in VCV utterances. *Journal of the Acoustical Society of America, 39,* 151–168.

Saltzman, E. L., & Munhall, K. G. (1989). A dynamical approach to gestural patterning in speech production. *Ecological Psychology, 1,* 333–382.

Schourup, A. (1973). A cross-language study of vowel nasalization. *Ohio State University Working Papers in Linguistics, 15,* 190–221.

Selkirk, E. O. (1982). The syllable. In H. van der Hulst and N. Smith (Eds.), *The Structure of Phonological Representations* (Part 2, pp. 337–383). Dordrecht, Netherlands: Foris.

Stetson, R. H. (1951). *Motor Phonetics: A Study of Speech Movements in Articulation.* (2nd ed.). Amsterdam: North Holland.

Tatham, M. A. A. (1970). A speech production model for synthesis by rule. *Working Papers in Linguistics* (Columbus: Ohio State University, Computer and Information Services Research Center), *6.*

Ushijima, T., & Sawashima, M. (1972). Fiberscopic examination of velar movements during speech. *Annual Bulletin Research Institute of Logopedics and Phoniatrics, University of Tokyo, 6,* 25–38.

Vaissière, J. (1988). Prediction of articulatory movement of the velum from phonetic input. *Phonetica, 45,* 122–139.

Vatikiotis-Bateson, E., & Fowler, C. A. (1988). Kinematic analysis of articulatory declination. *Journal of the Acoustical Society of America, 84,* S128 (At).

Vayra, M., & Fowler, C. A. (1992). Declination of supralaryngeal gestures in spoken Italian. *Phonetica, 49,* 48–60.