STRESS AND BOUNDARY EFFECTS ON ANTICIPATORY AND PRESERVATORY NASAL AIRFLOW

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ABSTRACT

The present study examined the effects of boundary strength and stress on nasal coarticulation with neighboring segments. Acoustic and nasal airflow data were recorded from four speakers as they produced intervocalic fricative-nasal and nasal-fricative sequences that spanned a word-internal boundary or a word boundary under two different stress conditions. Although neither stress nor boundary affected preservatory nasal airflow, tautosyllabic stress was associated with increased anticipatory nasal airflow within a word, but not at the a word boundary where coarticulation decreased or stayed the same. The interaction between boundary strength and stress was attributed to condition-dependent differences in the relative durations of individual segments. Overall, the study suggests that stress-induced lengthening of a velar gesture results in the leftward spread of nasality if adjacent segments are not also substantially lengthened by prosodic factors.

Keywords: boundary type, stress, anticipatory and preservatory coarticulation, nasalization

1. INTRODUCTION

Prosodic boundaries and lexical stress are two well known factors that influence articulatory timing in English. Consonants and vowels are lengthened at word and phrase boundaries [2, 7, 8, 9] and are longer in stressed syllables than in unstressed syllables [8, 12, 14]. Since boundary adjacent and stress induced lengthening typically affect the acoustic duration of several adjacent segments, lengthening may arise from the uniform expansion of articulatory movement within some suprasegmental unit. If this is the case, then stronger prosodic boundaries and stress might also reduce segment-to-segment overlap both within and between affected suprasegmental units. A few articulatory models of speech prosody make exactly this prediction.

For instance, Byrd & Saltzman [3] argued that boundary adjacent lengthening can be understood to result from a general slowing of the rate at which articulatory gestures are cued for output around prosodic boundaries. Insofar as gestures have intrinsic durations, a slower cueing rate results in reduced gestural overlap or coarticulation.

As for stress induced lengthening, de Jong's [4] model of localized hyperarticulation suggests that lengthening results from better and more extreme targeting of consonants and vowels within a syllable. An implication of such a model is that stress will also reduce coarticulation between segments within a syllable [5].

In spite of its intuitive appeal, the prediction that prosodic strengthening reduces coarticulation has not been systematically explored. Both boundary strength and stress are frequently manipulated in studies of coarticulation, but their effects are not well understood. For example, Moll & Daniloff [11] found no effect of boundary strength on nasal coarticulation in CVVN sequences, but other studies suggest that stronger boundaries may decrease anticipatory velar coarticulation (e.g., [6], [10]; but see [1] for evidence consistent with both findings). Regarding stress, Solé [13] found that nasalization began early in CVVN nonwords that had second syllable stress, but the effects of first syllable stress were not explored. Zajac *et al*. [16] found that stress on the second vowel of VCV nonwords sometimes decreased anticipatory nasal airflow compared to an "equal stress" condition, but it is unclear how the English-speaking participants realized equal stress.

In the present study, boundary strength and stress were systematically manipulated in order to explore prosodic effects on anticipatory and preservatory nasal coarticulation. Our working hypothesis was that stress and boundary strength would reduce coarticulation because they would uniformly expand articulatory movement within suprasegmental units.

2. METHOD

Four native speakers of English (three female, one male) participated in the study. All had some training in linguistics and all reported normal hearing.

2.1. Stimuli

Nonword stimuli were designed with two specific goals in mind. The first was to assess the effect of boundary type on anticipatory and preservatory nasal coarticulation. Stimuli were designed so that the nasal consonant occurred either at a word-internal syllable boundary or at a word boundary. The same VCCV sequences were used in both conditions, but the sequences were embedded in a VCVC#CVCV nonword sequence in the word boundary condition (e.g., *afna* and *abaf naba*).

The second goal was to assess the effects of stress on coarticulation. To this end, speakers were presented with accented versions of the nonword stimuli. The accented VCCV sequences were to be produced either with weak-strong or strong-weak stress. In the word boundary condition, the weak-strong and strong-weak patterns were realized in the strong-weak and weak-strong speaking conditions, respectively (i.e., WS, *ábaf nába*; SW, *abáf nabá*).

The VCCV sequences had one of three possible vowels (/i, a, u/) and one of two consonant sequences: fricative-nasal (FN, e.g., *afna*) or nasal-fricative (NF, e.g., *anfa*). The fricatives were /f/ and /θ/ and the nasals were /m/ and /n/. These consonants were selected because they never form legal onsets in English, ensuring that only heterosyllabic effects on consonant-consonant coarticulation were examined (e.g., *afna* → *af.na*, *anfa* → *an.fa*).

2.2. Procedure

Acoustic and nasal airflow data were simultaneously recorded using the Scicon two transducer interface system with a built-in microphone. The system was connected to a PC and calibrated according to manufacturer specifications. Participants were fitted with both an oral and nasal mask during recording, but only the nasal airflow data were analyzed.

Speakers produced the one- and two- word stimuli in the frame sentence *Write* ____ *twice*. Speakers read the phrases from a randomized list, which contained three repetitions of each stimulus item, yielding a total of 72 stimuli. A speaker produced the list using either a weak-strong or strong-weak stress pattern on one day, and returned to the lab on another day to record the same stimuli from a different randomized list using the other stress pattern. Speakers were given ample time to practice the stimuli using a given stress pattern before recording began. If the experimenter perceived a mispronunciation (either phonemic or prosodic), speakers were asked to produce the target again.

2.3. Measurements

Data were analyzed using Scicon's *PCquierer* software. The acoustic data were displayed as an oscillogram, which was time-locked with the nasal airflow track. Before measurements were taken, the nasal airflow track was smoothed to remove evidence of individual glottal pulses.

V1, V2, and the fricative were segmented using the oscillogram. Vowel onset was taken as the first clearly repeating voicing cycle and offset at the end of the last clearly repeating voicing cycle. When the vowel abutted the nasal consonant, the onset or offset were determined by abrupt amplitude and spectral changes in the waveform, providing for easy segmentation. Fricatives' onsets and offsets were taken at the beginning/end of the aperiodic noise associated with frication. The onset and offset of the nasal consonant were measured from the nasal airflow track. Nasal airflow was considered to be present when the flow rate exceeded 10 ml/sec [15].

Coarticulation between the nasal consonant and an adjacent segment was operationalized as the proportion of nasal airflow that occurred during the articulation of the adjacent segment. Thus, the duration of the nasalized portion of the fricative or vowel was divided by the total duration of the fricative or vowel. The greater the resulting proportion, the greater the nasalization of the adjacent segment, and so, the greater the coarticulation between the two segments.

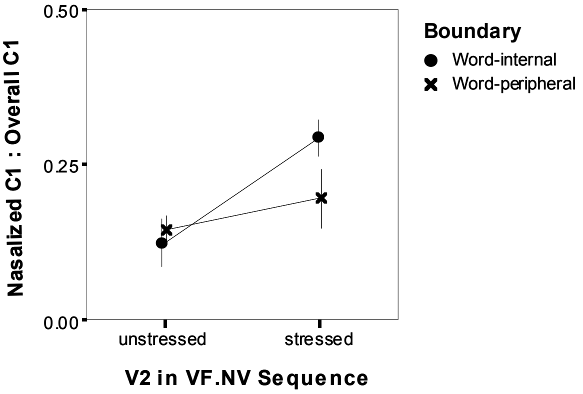
3. RESULTS AND DISCUSSION

Boundary strength and stress affected anticipatory coarticulation, but not preservatory coarticulation. Regarding anticipatory coarticulation, the findings were that first syllable stress increased fricative and vowel nasalization within a word, but not at a word boundary. This interaction between boundary type and stress appeared to result from the combined effects of word position and stress on velic and segmental durations.

3.1. Consonant-Consonant Coarticulation

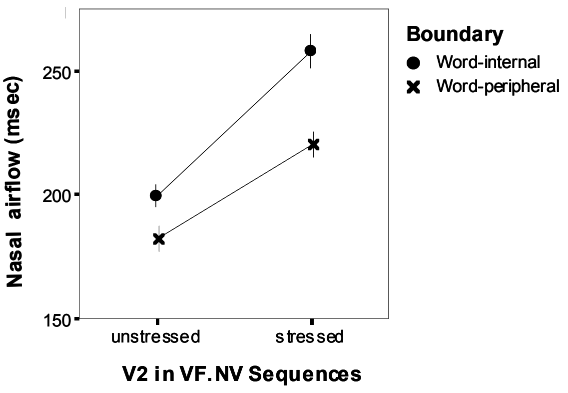
In a first analysis, the data were split by sequence type so that anticipatory (FN) and preservatory (NF) coarticulation could be examined separately. The two-way (boundary × stress) repeated measures ANOVAs revealed no significant effects of boundary or stress on preservatory coarticulation, but a significant effect of stress on anticipatory coarticulation [$F(1,143) = 9.24$, $p < .01$]. This effect was different for word-internal sequences than for those that crossed a word boundary [$F(1,143) = 4.25$, $p < .05$] as shown in Figure 1. A weak-strong stress pattern increased anticipatory nasal airflow within a word, but not across a word boundary.

Figure 1. Fricative nasalization in intervocalic FN sequences as a function of V2 stress and word position.



The results on overall nasal airflow duration paralleled to some extent the results on anticipatory coarticulation in FN sequences. A two-way repeated measures ANOVA on nasal airflow duration in intervocalic FN sequences revealed significant effects of boundary [$F(1,143) = 39.17$, $p < .01$], stress [$F(1,143) = 88.56$, $p < .01$], and boundary × stress [$F(1,143) = 4.47$, $p < .05$]. As shown in Figure 2, nasal airflow duration was increased when the tautosyllabic vowel (V2) was stressed. The increase was greater word-internally than across a word boundary. Also, nasal airflow duration was longer overall word-internally than across a word boundary.

Figure 2. Nasal airflow duration in intervocalic FN sequences as a function of V2 stress and word position.



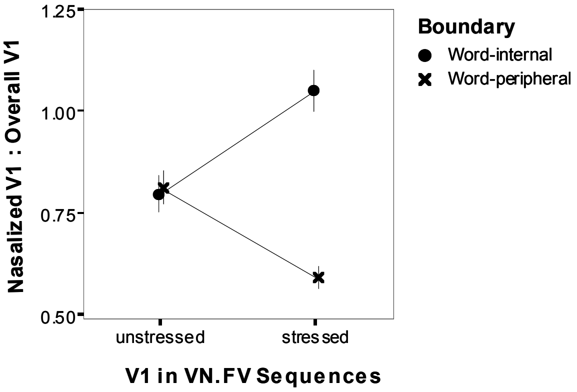
A nearly inverse pattern of results was obtained for fricative duration. Unlike nasal airflow, fricatives were longer at a word boundary than word-internally [$F(1,143) = 55.45$, $p < .01$]. Like nasal airflow duration, tautosyllabic stress increased fricative duration, but fricatives were tautosyllabic with V1 rather than with V2. This means that fricatives were longer when V1 was stressed and V2 was unstressed than when V2 was stressed and V1 was unstressed [$F(1,143) = 23.34$, $p < .01$]. Boundary strength did not interact with the effect of stress.

Together, the duration results suggest an explanation for why anticipatory coarticulation differed with boundary strength. Word-internally, stress induced lengthening of nasal airflow corresponded with a significantly shorter fricative, resulting in greater velic overlap. Across a word boundary, longer fricatives and relatively shorter velic gestures minimized the degree to which the velic gesture overlapped with the fricative.

3.2. Vowel-Consonant Coarticulation

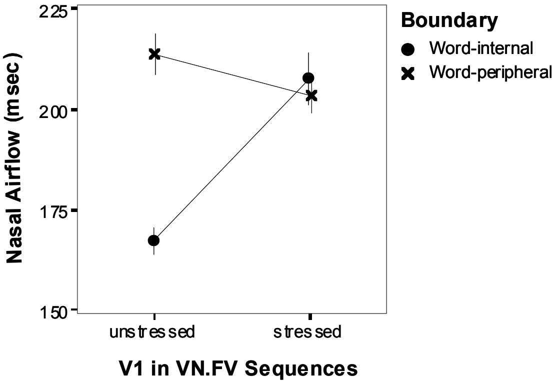
Once again, the data were split by sequence type so that anticipatory (VN) and preservatory (NV) coarticulation could be examined separately. The two-way (boundary × stress) repeated measures ANOVA indicated no significant effects of boundary type or stress on preservatory coarticulation, but significant effects of boundary [$F(1,143) = 19.51$, $p < .01$] and boundary × stress [$F(1,143) = 55.65$, $p < .01$] on vowel nasalization. The results indicated that anticipatory nasal airflow increased with tautosyllabic stress within a word, but decreased with stress at a word boundary (see Figure 3). The simple effect of stress was not significant.

Figure 3. Vowel nasalization in VN sequences as a function of V1 stress and word position.



The effects of boundary and stress on nasal airflow duration were partially consistent with the results on anticipatory airflow. Figure 4 shows the significant effects of boundary [$F(1,143) = 19.37$, $p < .01$], stress [$F(1,143) = 11.65$, $p < .01$], and boundary × stress [$F(1,143) = 24.02$, $p < .01$] on the duration of nasal airflow. In particular, tautosyllabic stress significantly increased nasal airflow duration in word-internal position, and decreased airflow duration at the word's edge.

Figure 4. Nasal airflow duration in VN sequences as a function of V1 stress and word position.



The origin of the anticipatory patterns shown in Figure 3 becomes clearer when one considers that although stress always increased V1 duration [$F(1,143) = 91.51, p < .01$], V1 duration was always longer in word final position than in word initial position [$F(1,143) = 545.33, p < .01$]; thus, there was an interaction between boundary and stress with respect to V1 duration [$F(1,143) = 24.02, p < .01$].

When the results on nasal airflow duration and V1 duration are summed, they provide an explanation for the pattern of anticipatory vowel nasalization shown in Figure 3. Relatively short velic gestures overlapped with relatively short V1 gestures in unstressed word-internal VN sequences, and relatively longer velic gestures overlapped to the same degree with the relatively longer V1 gestures associated with unstressed word-final VN sequences. By contrast, the word-internal and word-final velic gestures were equally long in stressed syllables, but V1 durations were significantly longer before word-final nasals than before word-internal nasals. This difference in vowel length led to differences in anticipatory overlap between V1 and nasal airflow: vowel nasalization was greater in word-internal VN sequences than in VN sequences at a word boundary.

4. CONCLUSION

The current study was motivated by the hypothesis that prosodic strengthening uniformly expands articulatory gestures within suprasegmental units thereby reducing segment-to-segment coarticulation. This hypothesis was only partially supported by the results. Boundary strength and stress had no effect on preservatory coarticulation and inconsistent effects on anticipatory coarticulation. In particular, stress increased anticipatory coarticulation within a word, but sometimes decreased anticipatory coarticulation at a word boundary. The duration results indicated that the different effects were attributable to different patterns of lengthening within and between words. Overall, the results suggest that uniform segmental lengthening within a syllable reduces anticipatory coarticulation, but that such uniform lengthening is only truly characteristic of word-final sequences in stressed syllables.

5. REFERENCES

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