# Prosodic strengthening on consonantal nasality and its asymmetric coarticulatory influence on vowel nasalization in CVN# and #NVC in English

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## ABSTRACT

This study explores the relationship between prosodic strengthening and linguistic contrasts in English by examining temporal realization of nasals in CVN# and #NVC, and their coarticulatory influence on vowels. Results show that different sources of prosodic strengthening bring about different types of linguistic contrasts. Prominence increased N-duration ([nasality]) but the vowel's [orality] (rather than [nasality] due to coarticulation) even when the nasal was phonologically focused (e.g., *mob-bob; bomb-bob*). Boundary strength reduced the nasal's [nasality] in domain-initial position (enhancing its [consonantality]), while the opposite was true with the *domain-final* nasal. In dynamical terms, these results may be seen as coming from differential intergestural coupling relationships that may underlie the difference in V-nasalization in CVN# *vs*. #NVC. It is proposed that the timing initially determined by such relationships must be modulated by prosodic strengthening in a way that reflects the relationship between dynamical underpinnings of speech timing and linguistic contrasts.

**Keywords**: prosodic strengthening, nasality, vowel nasalization, English, focus, boundary strength

## 1. 1. INTRODUCTION

Recent years have increasingly witnessed that fine-grained phonetic details of segments that arise at a subphonemic level may serve as important phonetic hallmarks of a higher-ordered linguistic structure of an utterance. Prosodic structure is one such linguistic structure that modulates phonetic shaping of segments with dual phonological functions: prosodic boundary and prominence marking ([1, 2, 3, 4]). Thus, exploration of effects of prosodic structure on phonetic realization illuminates the intricate interplay between low-level phonetic detail and higher-order linguistic information ([3, 4]). In an effort to understand the phonetics-prosody interplay, researchers have explored phonetic manifestations of prosodic structure in terms of *prosodic strengthening* associated with prosodic landmarks such as prosodic domain edges and syllables with prominence ([5, 6, 7, 8, 9, 10, 11, 12, 13]). Segments in these prosodic landmarks are generally known to be produced 'strongly.' Given that the 'strong' articulation is likely to heighten the phonetic clarity of the segments, one of the important questions has been how prosodic strengthening is related to linguistic contrasts ([7, 13]).

The present study continues to explore this issue by examining effects of prosodic structure on the acoustic realization of nasal consonants in CVN# and #NVC in English. Nasals are of particular interest because their fine-phonetic detail can be understood not only in terms of variation of the nasal segment itself but also in the way their nasality is coarticulated with neighbouring vowels in differing directionality (i.e., anticipatory (CVN) *vs*. carryover (NVC)). The goal of the present study is therefore to explore (1) how the acoustic temporal realization of English nasal consonants and their coarticulatory influence on the neighbouring vowel (as measured by A1-P0) are modulated by prosodic strengthening in CVN# versus #NVC, and (2) how the fine-phonetic detail associated with prosodic strengthening may be understood in terms of linguistic contrasts.

An important theoretical consideration concerns the nature of contrast enhancement that may arise with prosodic strengthening. Given that boundary and prominence markings are characterized by different phonetic hallmarks, the nature of linguistic contrasts that may be mediated by prosodic strengthening is also likely to differ (e.g., [7, 11, 13]). For example, boundary marking is often taken to be structurally motivated, resulting in enhancement of *syntagmatic contrast* between neighbouring segments at prosodic junctures. Prominence marking, on the other hand, is assumed to enhance *paradigmatic contrast*, which results in a maximization of phonological distinction of contrastive sounds. In connection with these distinctions, the following hypotheses can be made.

If prominence enhances 'paradigmatic' (phonological) contrast, the duration of the nasal murmur (N-duration) is expected to be lengthened which may be interpreted as an enhancement of [nasality]. At the same time, the nasal under prominence may also exert their coarticulatory influences more on the neighbouring vowels (*coarticulatory aggression*, e.g., [14, 15]), which is to be reflected in greater degree of V-nasalization. To test the prominence effect, three focus conditions were employed: lexical focus, phonological focus and no focus. It was important to test lexical versus phonological focus conditions, given that the enhancement of [nasality] may be achieved only when focus was made on the nasality of the consonant (phonological focus; 'mob' *vs*. 'bob' or 'bomb' *vs*. 'bob') rather than on the lexical (semantic) contrast ('bomb' *vs*. 'war') (cf. [7]).

The boundary effect, on the other hand, is expected to enhance *syntagmatic contrast* between the consonant and the neighbouring vowels. Under this hypothesis, [consonantality] is assumed to be enhanced with an increase in voicelessness rather than sonority (e.g., [16, 17, 18]). Thus, N-duration is expected to be shortened domain-initially (in #NVC) along with a reduction of its coarticulatory influence on the following vowel, which together is interpretable as enhancement of CV contrast. Yet, a different assumption can be made with the domain-'final' nasals (in CVN#) as the final consonant is generally subject to weakening rather than strengthening ([17, 19]). The consonantal weakening may then be acoustically expressed in a direction to increase sonority, hence longer N-duration and more V-nasalization.

Another theoretical consideration is concerned with how the observed acoustic variation due to prosodic structure can be understood in dynamical terms. Generally observed asymmetric syllable position effects on V-nasalization (more in CVN# than in #NVC) may be understood as coming from differential intergestural coupling relationships (anti-phrase *vs*. in-phase, respectively), which, in theory, determines the timing between the consonantal constriction gesture and the velum lowering gesture ([20, 21]; cf. [22]). Under this assumption, any observed systematic variation in V-nasalization due to prosodic strengthening can be taken to ensue from a fine tuning of intergestural timing as a function of prosodic structure (e.g., [21, 22]). The present study will allow us to explore how this may be the case in connection with the enhancement of linguistic contrasts that may underlie prosodic strengthening.

## 2. METHOD

Eight native speakers of American English, who were in their 20s and 30s, participated in the experiment.

The test words included four words (*palm, bomb, ten, den*) in CVN# and four words (*mop, mob, net, Ned*) in #NVC ('#' = an IP or a Wd boundary). As shown in Table 1, these words (underlined) were embedded in carrier sentences in a mini discourse situation where Boundary (IP/Wd) and Focus (LexF, PhonF, UnF) were systematically manipulated.

In the experiment, the subjects were presented with each mini dialogue on a computer screen, and the prime sentence (Speaker A, pre-recoded by a native speaker) was played back from a loudspeaker. The subjects then read the target sentence (as Speaker B) in response to the prime sentence presented auditorily as well as visually. In order to induce different types of focus, the subjects were asked to make contrast between words in bold in Sentences A and B, so that they made corrective lexical contrastive focus (e.g., *WAR vs. BOMB*) or corrective phonological contrastive focus on the nasal consonant (e.g., *BOB vs. BOMB*). For boundary conditions, an IP boundary was induced by placing a tag question after the test word (Table 1, (1)-(3)) or by placing a short utterance "Not exactly" before the test word (Table 1, (7)-(9)). The Wd boundary was induced by placing the test word in the middle of a short phrase "*say [XXX] fast again*" (Table 1, (4)-(6)).

**Table 1.** An example set of test words (underlined) with varying focus and boundary conditions. .

**CVN#, IP-final**
(1) A: Were you supposed to write "***WAR***"?
B: No. I was supposed to write "***BOMB***", wasn't I? (**LexF**)
(2) A: Were you supposed to write "***BOB***"**?**
B: No. I was supposed to write "***BOMB***", wasn't I? (**PhonF**)
(3) A: Were **YOU** supposed to write "*bomb*"?
B: No. **JOHN** was supposed to write "*bomb*", wasn't he? (**UnF**)

**CVN#, Wd-final (IP-medial)**
(4) A: Did you write "*say **WAR** fast again*"?
B: No. I wrote "*say **BOMB** fast again*". (**LexF**)
(5) A: Did you write "*say **BOB** fast again*"?
B: No. I wrote "*say **BOMB** fast again*". (**PhonF)**
(6) A: Did you write "*say bomb **FAST** again*"?
B: No. I wrote "*say bomb **SLOWLY** again*". (**UnF**)

**#NVC, IP-initial**
(7) A: Did you write "***GANG** fast again*"?
B: Not exactly. "***MOB** fast again*" was what I wrote. (**LexF**)
(8) A: Did you write "***BOB** fast again*"?
B: Not exactly. "***MOB** fast again*" was what I wrote. (**PhonF**)
(9) A: Did you write "*mob **FAST** again*"?
B: Not exactly. "*Mob **SLOWLY** again*" was what I wrote. (**UnF**)

**#NVC, Wd-initial (IP-medial)**
(similar to Wd-final (IP-medial) sentences in CVN#)

The recording was made in a sound-attenuated booth, using a SHURE VP88 44 condenser microphone and a Tascam DR-680 digital recorder at a sampling rate of 44 kHz. In total, 1,536 sentence tokens were collected (8 items x 2 boundaries x 3 focus types x x 4 repetitions x 8 speakers). Out of these, 83 tokens were discarded due to unintended prosodic boundaries (as agreed by three authors) and measurement errors for A1-P0, so that 1453 tokens were included for the analyses.

Acoustic measurements included N-duration (duration of nasal consonants, /n/ or /m/) and A1-P0 (A1=amplitude of F1; P0=amplitude of the spectral nasal peak in the vicinity around 250 Hz) (e.g,. [24, 25, 26]). A1-P0 was taken from the midpoint of the vowel as an index of V-nasalization (the lower, the more nasalized). (A1-P0 measured in other portions of the vowel is not reported here.)

## 3. RESULTS

Statistical evaluations of effects of Syll-Position (final/coda, initial/onset), Focus (LexF, PhonF, UnF) and Boundary (IP, Wd) were made based on repeated measures ANOVAs with posthoc comparisons (with Bonferroni corrections) for further analyses of within-factor effects.

### 3.1 Nasal Consonant Duration (N-duration)

N-duration was significantly influenced by all three prosodic factors with interactions in all possible ways each at *p*<.001. Most clear effects were found with Syll-Position and Focus: N-duration was longer in #NCV than in CVN# (F[1,7]=30.4, p<.001) (compare the right *vs*. left panels in Figure 1(a)), and it was longer when focused (both lexical and phonological) than when unfocused (F[1,14]=109.6, p<.001), but with no difference between lexical and phonological focus.

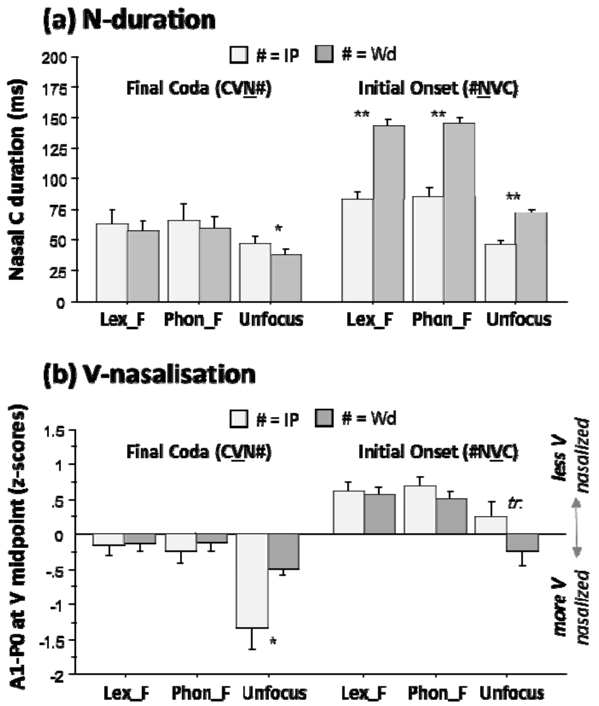
Variation in N-duration, however, is more complex in association with Boundary. There was a main effect of Boundary (F[1,7]=23.5, p<.005), but with a Boundary x Syll-Position interaction (F[1,7]=169.5, p<.001) and a three-way interaction (F[2,14]=28.1, p<.001). The Boundary x Syll-Position interaction stemmed from an asymmetric boundary effect on N-duration in CVN# *vs*. #NVC. As can be inferred from Fig. 1(a), N-duration in CVN# tended to be longer IP-finally than Wd-finally (p<.08) in line with a domain-final *lengthening* effect, but the opposite was true in #NCV, showing a domain-initial *shortening* effect (i.e., *shorter* IP-initially than Wd-initially, p<.001). However, posthoc comparisons associated with the three-way interaction revealed that the *final lengthening* effect in CVN# was significant only in the unfocused condition (p<.05; see Fig.1(a), left), whereas the *domain-initial shortening* effect in #NVC was robust across focus conditions (see Fig.1(a), right).

### 3.2 A1-P0: Degree of V-nasalization

There was a significant main effect of Syll-Position on A1-P0 (F[1,7]=34.5, p<.001), with lower A1-P0 in CVN# than in #NVC (compare the left *vs*. right panels in Figure 1(b)), indicating a greater degree of V-nasalization in the anticipatory (CVN#) than in the carryover (#NVC) direction. There was also a significant main effect of Focus (F[2,14]=15.5, p<.005), with less V-nasalization (i.e., coarticulatory resistance) when focused than unfocused, while no difference was observed between lexical and phonological focus. This focus effect was observed in both directions (CVN# and #NVC at p<.05, Figure 1(b)), showing vowels' coarticulatory resistance to nasalization under prominence (focus).

The Boundary factor yielded no main effect on A1-P0 (F[1,7]<1), but as was the case with N-duration, Boundary interacted with Syll-Position (a trend effect: F[1,7]=4.8, p<.07): V-nasalization tended to be *more* IP-finally (showing *coarticulatory vulnerability* in CVN#), but *less* IP-initially (showing *coarticulatory resistance* in #NVC). The asymmetric coarticulatory pattern is reliable only in the unfocused condition (Figure 1(b): CVN#, p<.05; #NVC, p<.07). That is, only in the absence of the focus effect, the influence of boundary strength became effective on V-nasalization.

**Figure 1**: (a) Nasal Consonant Duration; (b) Degree of V-nasalization as reflected in A1-P0 (z-scores). '*' = p<.05; '**'=p<.001, 'tr' = .05<p<.08



## 4. SUMMARY AND DISCUSSION

One of the basic findings was that N-duration was much shorter in the coda (CVN#) than in the onset (#NVC) in line with previously observed articulatory weakening of final consonants (e.g,. [17, 19]). Despite the shorter N-duration in CVN# (than in #NVC), however, the degree of V-nasalization was still greater in CVN# (than in #NVC), which is consistent with the general observation in the coarticualtory literature (i.e., more V-nasalization in the anticipatory (CVN) than in the carryover (NVC) direction [22, 27]). The asymmetric pattern due to syllable position is also accountable in dynamical terms—i.e., by differential coupling relationships of the velum lowering gesture and the oral constriction gesture (relatively earlier *vs.* later velum lowering gesture due to anti-phase *vs.* in-phase intergestural couplings [20, 21]).

As for prominence effects, N-duration was lengthened under focus, which may be interpreted as enhancing the consonant's [nasality]. But phonological focus on the nasal was no better than lexical focus in increasing N-duration. More crucially, V-nasalization *decreased* when focused (in both anticipatory or carryover coarticulation), even when the nasal consonant was phonologically focused—i.e., in an environment in which the nasal's coarticulatory aggression on the neighbouring vowels is expected to be greater (e.g., [14, 15]). This means that the focus-induced modification of V-nasalization worked, if anything, against enhancement of [nasality]. From the dynamical perspective, although the timing between the oral and velic gestures is assumed to differ between CVN and NVC (with anti-phase *vs.* in-phase couplings), prominence (focus) was found to influence the intergestural timing in a unified way—i.e., by reducing V-nasalization regardless of directionality (CVN/NVC) and focus type (lexical/phonological). This implies that the timing between the oral and velic gestures initially determined by differential coupling relationships are further fine-tuned by prominence in a linguistically significant way to enhance linguistic contrasts—e.g., the [orality] feature of the vowel in the present case.

Effects of Boundary were in sharp contrast between domain-final and domain-initial positions. N-duration was significantly shortened domain-initially (*vs.* domain-medially), but tended to be lengthened domain-finally (*vs.* domain-medially). The domain-initial shortening of N-duration is interpretable as enhancing the [consonantality] feature (the lesser the nasality, the more the consonantality) ([16, 18, 19]), while the domain-final lengthening of N-duration reflects a local slowing down at a prosodic juncture [23]. A similar asymmetry was found with V-nasalization: Vowels were coarticulated with nasals *less* domain-initially, but *more* domain-finally (than domain-medially). These results suggest that the boundary effect on the *domain-initial* nasal enhances the nasal's [consonantality] rather than its [nasality], enhancing CV (syntagmatic) contrast. On the other hand, the boundary effect on the *domain-final* nasal appears to be better characterized as 'weakening' of [consonantality]—i.e., the increase of both N-duration and V-nasalization in CVN# is likely to increase the consonant's sonority, thus weakening its consonantality. On a speculative note, it appears that the weakening of consonantality allows for a loosening of the articulatary linkage of the oral constriction and the velum lowering gesture, which may account for more nasal coarticulation in domain-final position. This is consistent with the assumption that the intergestural timing is less stable in an anti-phase mode than in an in-phase mode, allowing for more coarticulatory flexibility in CVN#.

Another noteworthy point is that boundary interacted with prominence, such that the boundary effect, especially on V-nasalization, was reliable only in the absence of focus. This suggests that the coarticulatory resistance force under focus takes precedence over the boundary effect (as a kind of ceiling effect), and boundary takes effect only in the absence of prominence (cf. [10, 13]). Crucially, however, the boundary effect on V-nasalization was still asymmetric with coarticulatory resistance in #NVC *vs.* coarticulatory vulnerability in CVN#. Again in dynamical terms, this has an implication for the theory of pi-gesture (e.g., [23]) in that the local slowing-down of articulatory movement at a prosodic juncture (as assumed by the theory) must be modulated differentially in order to account for the asymmetric boundary effects on the intergestural timing in CVN# (with anti-phase coupling) *vs.* #NVC (with in-phase coupling) (see [21] for related discussion).

In conclusion, the present study showed that prosodic strengthening is differentially reflected in N-duration and V-nasalization, depending on its source. The prominence-induced strengthening increases the [orality] feature of the vowel (rather than [nasality] of the consonant) even when focus fell on the nasal. On the other hand, the boundary-induced domain-initial strengthening effect increases the nasal's [consonantality] through its shortening and reduction of coarticulatory exertion on the following vowel. Yet, this boundary effect on *initial* nasals was in sharp contrast with the boundary effect on *final* nasals the latter of which is better characterized as weakening in their consonanality.

The results further imply that the assumed intergestural coupling relationships between the oral and velic gestures are modulated by prominence and boundary, which can be understood in terms of the relationship between dynamical underpinnings of speech timing and linguistic contrasts.

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