Focus and boundary effects on coarticulatory vowel nasalization in Korean with implications for cross-linguistic similarities and differences

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Abstract: This study investigates focus and boundary effects on Korean nasal consonants and vowel nasalization. Under focus, nasal consonants lengthen in CVN# but shorten in #NVC, enhancing [nasal] vs [oral]. Vowels resist nasalization under focus, enhancing [oral]. Domain-initial nasal consonants denasalize, exercising no coarticulatory influence. Domain-final nasal consonants shorten counter to expectation, although vowel nasalization increases. Comparison with English data reveals similarities (focus-induced coarticulatory resistance) despite cross-linguistic differences in marking prominence, but it also suggests that prosodic-structural conditioning of non-contrastive vowel nasalization, albeit based on phonetic underpinnings of coarticulatory process, is fine-tuned in language-specific ways, resulting in cross-linguistic variation.

[MG]
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1. Introduction

Coarticulation is one source of phonetic variation due to inevitable overlap of multiple articulatory gestures in continuous speech (e.g., Kühnert and Nolan, 1999). This low-level process, however, is often fine-tuned in reference to higher-order linguistic structures such as the phonological contrast and the syllable structure of a language (e.g., Beddor *et al.*, 2002; Scarborough *et al.*, 2015). Another source of phonetic variation is prosodic structure. For example, segments can be strengthened in line with the degree of prominence and the boundary strength associated with the prosodic structure [see Cho (2016) for a review]. This prosodic strengthening effect also reflects the phonetics-prosody interface fine-tuned in a language specific way (e.g., Keating *et al.*, 2003).

The primary purpose of the present study is to explore how languages that differ in their prosodic and sound systems would manifest the prosodic-structural modulation of coarticulatory vowel nasalization. Addressing this question will illuminate the language specificity and the universality of the phonetics-prosody interface on the coarticulatory process. To this end, this study investigates the acoustic modulation of vowel nasalization in Korean as a function of prosodic strengthening factors such as prominence and boundary, and compares the results with those of a comparable study on English (Cho *et al.*, 2017).

The Korean prosodic system differs from the English prosodic system in several ways. First, they differ in their prominence marking systems (Jun, 2005). English employs a head-prominence system, in which a stressed vowel serves as the head of a prosodic unit bearing a pitch accent. Cho *et al.* (2017) reported that even when the (corrective) focus fell on the contrast between the nasal (N) vs the oral consonant in English (e.g., *mob* vs *bob*), the vowel showed coarticulatory resistance to vowel nasalization, enhancing its [oral] feature. Korean, in contrast, employs an edge-prominence

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system, in which the prominence tends to be marked by prosodic phrasing (e.g., Jun, 2005), and hence the vowel is not defined as the prominence head. Given the importance of the edge marking in Korean, the contrastive focus on N could be phonetically expressed directly on the edge consonant rather than on the vowel. This would increase the phonetic nasality of N, which might, in turn, increase its coarticulatory influence on the adjacent vowel, showing coarticulatory vulnerability rather than resistance. Alternatively, one cannot rule out the possibility that focus that stems from the information structure can directly modulate phonetic realization without being mediated by the accentuation system (e.g., Mücke and Grice, 2014), and therefore heightens the phonetic clarity of the vowel regardless of the prominence marking system of the language. If so, similar coarticulatory resistance effects would emerge across languages.

Second, the two languages also differ in the phonetic manifestation of boundary-related strengthening. In particular, Korean may show more robust initial strengthening on initial consonants, presumably because it is not constrained by stress (Keating *et al.*, 2003). Moreover, Korean undergoes a denasalization process in which the word-initial N tends to lose its nasality, even to the extent that non-native listeners would misperceive it as oral (Yoshida, 2008; Kim, 2011). The denasalization in Korean may well attenuate the vowel nasalization domain-initially to a greater degree than in English. This then leads to another question regarding how the initial N is realized under focus. If the denasalization process delinks the [nasal] feature, and the [oral] feature operates in the phonetic implementation, the effect may be reinforced under focus in a way to enhance the vowel's [oral]. Alternatively, if focus makes reference to the underlying [nasal], one would still expect an enhancement of nasality under focus.

In addition to testing these possibilities, the present study also explores a more general issue regarding how the coarticulatory process, which has its origin in biomechanic constraints imposed on the human speech production system, may vary across languages. Of particular interest is how articulatory declination that may occur toward the end of a phrase may be reflected in the degree of vowel nasalization (cf. Krakow, 1993). Cho *et al.* (2017) reported that vowels in phrase-final CVN in English become vulnerable to the coarticulatory influence of N, possibly due to an articulatory weakening of the oral gesture that involves the velum raising. Given that a seemingly non-contrastive phonetic variation may be systematicized in the phonetic grammar of the language (cf. Cho and Ladefoged, 1999), it remains to be seen exactly how the two languages would differ in phonetic implementation of vowel nasalization.

To address these issues, the present study examines the acoustic realization of N (its duration and energy) and the degree of vowel nasalization (to be reflected in a spectral tilt measure of A1-P0) in #NVC and CVN# (where "#" refers to a prosodic boundary) as a function of boundary strength and focus, as will be explained in Sec. 2.

2. Method

2.1 Participants, speech materials, and recording procedure

Twelve native speakers (7F, 5M) of standard (Seoul) Korean participated for pay. All of them were undergraduate students in their 20s (age range, 21–28; mean, 24.4).

There were eight monosyllabic target words in the nasal context with four in CVN and four in NVC [CVN: *p*am* ("washing"); *t*am* ("picking"); *p*an* ("washed"); *t*an* ("picked"); NVC: *mat* ("taste"), *mak* ("screen/curtain"), *nat* ("sickle"), *nap* ("lead")]. Eight additional CVC words in the oral (control) context were used, each of which constituted a phonological (phonemic) contrast in terms of the nasality vs orality of the consonant in the onset and the coda position (e.g., *mak* vs *p*ak*; *p*am* vs *p*ap*). As shown in Table 1, each word was embedded in a carrier sentence, which was an answer to a question in a mini discourse context. The interlocutors in the discourse pretended to play a type of board game designed to induce various focus and prosodic boundary conditions. To obtain semi-spontaneous speech, the full carrier sentences were not provided as written texts, but were illustrated on a computer screen. For example, there appeared two cards on the screen and a monosyllabic test word was written on each of them (*p*am* vs *p*ap*). The target word (e.g., *p*am*) appeared with an "O" mark, and its contrasting word (e.g., *p*ap*) with an "X" mark. The pre-recorded voice asked the subject whether the next word to pick would be one of the two words shown on the screen. The subject, knowing the answer, was supposed to correct it by saying that the other one should be picked, which induced contrastive (corrective) focus on the target word. In this way, the target words were either focused (by phonologically contrasting a nasal vs an oral stop, e.g., CVN#, *p*a**m*** vs *p*a**p***; #NVC, ***p****at* vs ***m**at*) or unfocused (by placing a contrastive focus on an adjacent word in a carrier sentence).

Table 1. Example sentences with target word *p*am* in the CVN# context. Target words are underlined and focused words are in bold.

Boundary	*Focus*	*Example sentences*
IP-final	*Focused*	A: [ipʌn tanʌnɯn k^{h}ɯnap*a **p*ap**ini]?
		"This time, is the word (card) big uncle's ***p*ap***?"
		B: [ani] IP [k^{h}ɯnap*a **p*am**] IP [twɛssʌ]?
		"No. It's big uncle's ***p*am***. Got it?"
	Unfocused	A: [ipʌn tanʌnɯn **tʃakɯn**ap*a p*amini]?
		"This time, is the word (card) **little** uncle's *p*am*?"
		B: [ani] IP [**k^{h}ɯn**ap*a p*am] IP [twɛssʌ]?
		"No. It's **big** uncle's *p*am*. Got it?"
Wd-final	*Focused*	A: [ipʌn tanʌnɯn k^{h}ɯnap*a **p*ap** twienonni]?
		"This time, do I place the word (card) to the right of big uncle's ***p*ap***?"
		B: [ani] IP [k^{h}ɯnap*a **p*am** twie] IP [twɛssʌ]?
		"No. To the right of big uncle's ***p*am***. Got it?"
	Unfocused	A: [ipʌn tanʌnɯn **tʃakɯn**ap*a p*am twienonni]?
		"This time, do I place the word (card) to the right of **little** uncle's *p*am*?"
		B: [ani] IP [**k^{h}ɯn**ap*a p*am twie] IP [twɛssʌ]?
		"No. To the right of **big** uncle's *p*am*. Got it?"

In the IP boundary condition, the target words were produced at the edges of an Intonational Phrase, as exemplified in the upper rows of Table 1. (Note that CVN# always occurred IP-finally, and #NVC IP-initially, as "#" indicates.) The target words were also produced in the middle of an IP (phrase-internal, Wd-final/initial condition) as in the lower rows of Table 1.

The carrier sentences were simple (e.g., No. It is big uncle's (TARGET). Got it?). In a practice session (about 30 min), participants went over the entire list of the test words at least once in carrier sentences in all experimental contexts. After the practice, participants could easily produce the carrier sentences as intended without the full written text, solely relying on the visual clues on the screen. During the experiment, participants heard pre-recorded prompt questions (Speaker A in Table 1) with the matching pictures on a screen, and they played a role of Speaker B, by answering the question as guided by the pictures.

Acoustic data were collected using a Tascam HC-P2 digital recorder and a SHURE KSN44 condenser microphone at a sampling rate of 44 kHz. Each dialogue was repeated 4 times in four different blocks, each of which contained all the test words in a different randomized order. A total of 3072 tokens were collected [i.e., 8 minimal pairs × 2 contrastive words (nasal, oral) × 2 focus types (focused, unfocused) × 2 boundary types (IP, Wd) × 4 repetitions × 12 speakers]. Two trained Korean ToBI transcribers initially examined the recorded tokens. Tokens that were produced with unintended prosodic boundaries or focus patterns were discarded as agreed by all three authors, which left 2894 tokens for further analyses. (We included all the IP-initial NVC test words in our analyses as it was important to test the degree of vowel nasalization even when N was substantially denasalized.)

2.2 Measurement

Acoustic duration of the nasal consonant (N-duration) was measured from the onset to the offset of the nasal murmur displayed on the spectrogram. Nasal energy (N-energy) was defined as the amplitude of P0 at the midpoint of the nasal murmur, i.e., the nasal peak around 250–300 Hz (cf. Chen, 1996). A1-P0 values were measured at multiple locations in the vowel both at relative time points (25%, 50%, 75% points during the vowel) and at absolute time points (20, 40, 60 ms after the vowel onset in NVC and before the vowel offset in CVN) (visit http://tcho.hanyang.ac.kr/jang-kim-cho-2018_supplementary for a figure that illustrates these measurement points). The absolute measures would indicate the extent to which coarticulatory vowel nasalization can be interpretable as a time-locked phenomenon, i.e., as a function of the "physical" distance from the source; whereas the relative measures would indicate the extent to which the coarticulatory effect can spread into the vowel as a process beyond a pure low-level phonetic effect (cf. Cho *et al.*, 2017). Following Zellou (2017), the A1-P0 values were then normalized for each participant: The minimum and maximum nasality values from each minimal pair (i.e., the A1-P0 difference in CVN#-CVC# and in

#NVC-#CVC) were used to set the nasality range of each pair, and the proportion (%) was calculated for each A1-P0 measure of the target word based on the nasality range. [See Garellek *et al.* (2016) for related measures.]

2.3 Statistical analyses

The effects of Focus and Boundary on N-duration, N-energy, and vowel nasalization were examined by Repeated Measures Analysis of Variance (RM ANOVA), using IBM SPSS Statistics 21.0. Time point (both relative and absolute) factors were added for the vowel nasalization measure. For the purpose of the present study, each speaker's data were averaged across repetitions and items, to obtain an aggregated representative value per condition per speaker. *Post hoc* one-way RM ANOVAs were carried out when significant interactions were observed.

3. Results

3.1 CVN# (domain-final) context

N-duration in CVN# [Fig. 1(a)] showed a main effect of Focus, being *longer* under focus, and a main effect of Boundary, being *shorter* IP-finally. N-energy [Fig. 1(b)] also showed similar patterns: it was *greater* under focus, but *weaker* IP-finally. No interaction between Boundary and Focus was found.

As for vowel nasalization in CVN#, vowels were *less* nasalized when focused [Fig. 2(a)], but *more* nasalized IP-finally [Fig. 2(b)]. There was also a significant main effect of Time point: vowel nasalization was greatest when the measurement point was most proximal to N, showing a phonetic proximity effect in both the relative and absolute measures [Figs. 2(a)–2(d)]. Crucially, Focus did not interact with Time point (in both measures) (relative, $F[2,22] = 1.89$, $p > 0.1$; absolute, $F[2,22] = 0.86$, $p > 0.1$). This indicates that the focus-induced coarticulatory resistance effect was pervasive throughout the vowel.

Boundary showed no interaction with Time point in the absolute measure ($F[2,22] = 0.06$, $p > 0.1$), again indicating the pervasiveness of the increased vowel nasalization throughout the vowel. There was, however, a significant interaction between Boundary and Time point in the relative measure ($F[2,22] = 5.13$, $p < 0.05$, $\eta_p^2 = 0.32$). The interaction was in part due to the fact that the boundary-induced vowel nasalization was most robust at the 50% point ($F[1,11] = 10.89$, $p < 0.01$, $\eta_p^2 = 0.5$), while the effect disappeared at the most distal (75%) point. At the nearest (25%) point, only a numerical difference due to Boundary was observed. [Note that the 25% point was physically more proximal to N in the Wd-final position (because the V-duration was short) than in the IP-final position. The physical proximity to N in the Wd-final condition may then have offset the coarticulatory effect in the IP-final condition.]

3.2 #NVC (domain-initial) context

Focus did not show a main effect on N-duration [Fig. 1(c)], but it did on N-energy [Fig. 1(d)], such that N-energy was weaker, indicating an increased degree of denasalization under focus. Boundary showed a main effect on both N-duration and N-energy [Figs. 1(c) and 1(d)], showing a boundary-induced weakening, i.e., IP-initially N in #NVC was shorter in N-duration and weaker in N-energy, again showing an increased denasalization. N-energy, however, showed a significant Focus × Boundary interaction ($F[1,11] = 34.64$, $p < 0.001$, $\eta_p^2 = 0.76$). This interaction was due in part to the fact that the weakening of N-energy due to Focus was significant only Wd-initially ($F[1,11] = 30.71$, $p < 0.001$, $\eta_p^2 = 0.736$, $\Delta = -11.5$ dB), and at the same time the weakening of N-energy due to

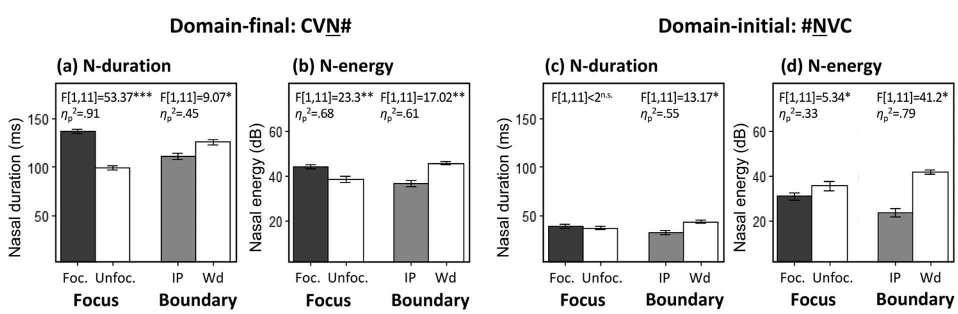

Fig. 1. Main effects of Focus and Boundary on N-duration and N-energy in CVN# (domain-final) context [(a) and (b)] and #NVC (domain-initial) context [(c) and (d)]. ***, **, *, and n.s. refer to $p < 0.001$, $p < 0.01$, $p < 0.05$, and $p > 0.05$, respectively.

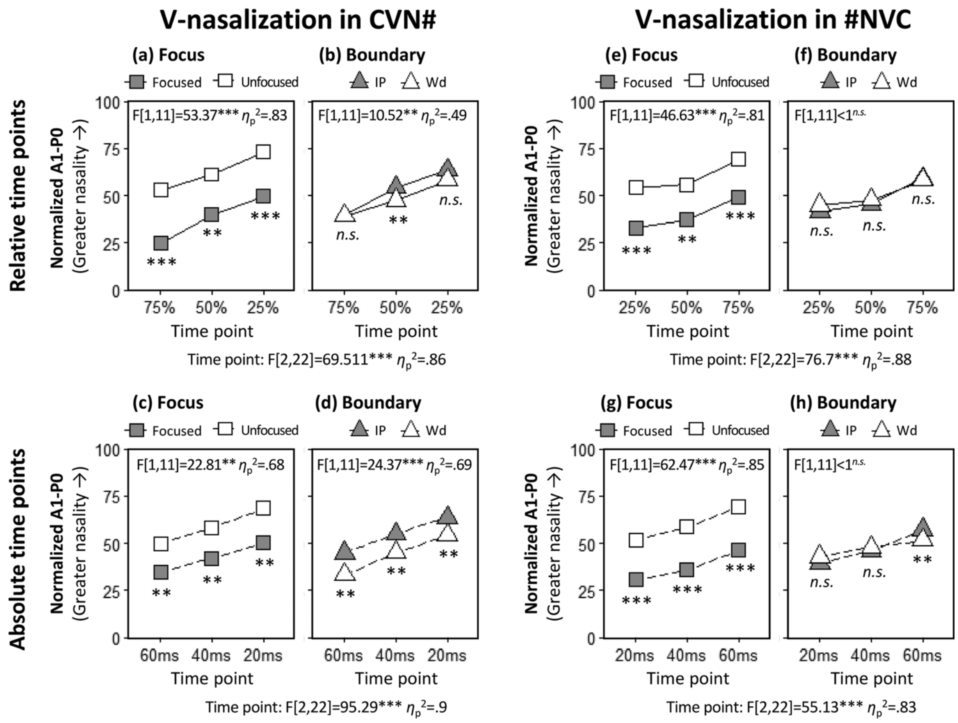

Fig. 2. Main effects of Focus and Boundary on vowel nasalization in CVN# (domain-final) context [(a)–(d)] and #NVC (domain-initial) context [(e)–(h)]. The upper row exhibits the effects in relative time points and the lower row in absolute time points. ***, **, and n.s. refer to $p < 0.001$, $p < 0.01$, and $p > 0.05$, respectively.

Boundary was more robust in the unfocused (vs focused) condition ($F[1,11] = 306.98$, $p < 0.001$, $\eta_p^2 = 0.95$, $\Delta = -25.6$ dB; $F[1,11] = 6.31$, $p < 0.05$, $\eta_p^2 = 0.37$, $\Delta = -10$ dB, respectively). In other words, the weakening effect of one factor was attenuated when the other factor also had a weakening effect, i.e., a kind of floor effect.

Turning to vowel nasalization in #NVC, there was a main effect of Focus in both the relative and absolute measures, showing a reduction of vowel nasalization under focus [Figs. 2(e) and 2(g)]. Crucially, the coarticulatory reduction was robust across all the measurement points of the vowel. This was further confirmed by no interaction between Focus and Time point in both measures (relative, $F[2,22] = 1.73$, $p > 0.1$; absolute, $F[2,22] = 0.21$, $p > 0.1$). However, Focus interacted with Boundary in the absolute measure ($F[1,11] = 5.159$, $p < 0.05$, $\eta_p^2 = 0.32$) and as a trend effect in the relative measure ($F[1,11] = 4.78$, $p < 0.06$, $\eta_p^2 = 0.3$). This interaction stemmed in part from the fact that vowels were less nasalized (due to focus) Wd-initially than IP-initially (relative, IP-final, $F[1,11] = 22.39$, $p < 0.01$, $\eta_p^2 = 0.67$; Wd-final, $F[1,11] = 39.58$, $p < 0.001$, $\eta_p^2 = 0.79$; absolute, IP-final, $F[1,11] = 25.51$, $p < 0.001$, $\eta_p^2 = 0.69$, Wd-final, $F[1,11] = 35.3$, $p < 0.001$, $\eta_p^2 = 0.76$).

Boundary, on the other hand, showed no main effect [Figs. 2(f) and 2(h)], nor did it show an interaction with Time point. This indicates no boundary-induced modification of vowel nasalization across the board. (Note, however, that one measurement point [i.e., the 60 ms point shown in Fig. 2(h)] showed a significant boundary effect, but given that there was no significant interaction between Boundary and Time point, we will not discuss this effect further.)

Finally, as shown in Figs. 2(e)–2(h), the nasality of the vowel in #NVC was the least at the 20 ms point and the 25% point that were most proximal to N (relative, $F[2,22] = 76.7$, $p < 0.001$, $\eta_p^2 = 0.88$; absolute, $F[2,22] = 55.125$, $p < 0.001$, $\eta_p^2 = 0.83$), and the nasality increased gradually afterwards, counter to the expected phonetic proximity effect. To examine the denasalization effect in comparison with the oral (#CVC) context, we ran additional RM ANOVAs with Consonant (NVC vs CVC), and found that there was no Consonant effect (relative, $F[1,11] = 3.12$, $p > 0.1$; absolute, $F[1,11] = 0.2$, $p > 0.1$), which indicated that the gradual increase in nasality in NVC was comparable to that in CVC, showing a robust denasalization effect. However, there was a significant two-way interaction between Consonant and Time Point (relative, $F[2,22] = 11.49$, $p < 0.001$, $\eta_p^2 = 0.98$; absolute, $F[2,22] = 20.23$, $p < 0.001$, $\eta_p^2 = 0.82$), indicating that the degree of vowel nasalization was greater for NVC than CVC at least in the earlier part of the vowel at the 25% point ($p < 0.05$) and at the 20 ms point (a trend effect, $p < 0.09$).

4. Summary and discussion

The results for CVN# indicate that focus strengthens the consonant's nasality in N-duration and N-energy. The augmented nasality of N under focus could have exerted a greater coarticulatory influence on the preceding vowel (in CVN#). But the reverse was true, i.e., vowel nasalization was greatly *reduced* under focus. The coarticulatory reduction effect was pervasive throughout the vowel, which was consistent with what was observed with English (Cho *et al.*, 2017), albeit the systemic difference in marking prominence between the two languages. This, as also discussed in Cho *et al.* (2017), suggests that the focus-induced coarticulatory reduction was not simply a localized low-level phonetic effect, but interpretable as coarticulatory resistance in reference to higher-order linguistic structures of the language, enhancing the vowel's [oral] feature. The similarity between the two languages further implies that the focus marking that stems from the information structure may directly operate on the phonetic realization of vowels regardless of the prominence marking system of the language. This is consistent with the view that the phonetic modulation due to focus may not be mediated by the presence or absence of pitch accent but it operates on the vowel directly regulated by the information structure (cf. Mücke and Grice, 2014).

The focus effect on #NVC, however, was different from that on CVN#. The nasality of the initial N was reduced in N-energy (while N-duration was not influenced). This was the exact opposite of what was observed with the initial N in English, which showed lengthening (Cho *et al.*, 2017). The apparent cross-linguistic difference could be accounted for by the denasalization process of initial N in Korean (e.g., Yoshida, 2008; Kim 2011). The results also imply that it is not the underlying [nasal] feature, but the derived [oral] feature that is enhanced under focus. It is also worth noting that the focus-induced reduction of N-energy and vowel nasalization in #NVC was more robust Wd-initially than IP-initially, showing an intricate interaction between Focus and Boundary.

Turning to the boundary-related effect, we also found cross-linguistic differences. The final N in CVN# in Korean did not show a final lengthening effect. It was in fact shortened and weakened IP-finally (as reflected in N-duration and N-energy, respectively). This was again the opposite of the phrase-final lengthening effect found in English. In contrast, Korean showed an increase in vowel nasalization IP-finally just as in English. Cho *et al.* (2017) attributed the increased vowel nasalization in English to a loosening of articulatory linkage between the oral constriction and the velum lowering gesture, which caused more nasal leaking during the vowel (hence more nasalization). The boundary-related coarticulatory effect in CVN# in Korean may also be understood by the same account. On the other hand, the IP-final shortening of N in Korean needs further elucidating. The shortening effect may be understood if we follow Beddor's (2009) assumption that coarticulatory variation in vowel nasalization occurs due to a relatively constant activation time of the velum lowering gesture which is variably aligned to the oral gestures. Under this account, when the velum lowering gesture overlaps more (or is aligned earlier) with the vocalic (vowel) gesture, the N-duration is likely to be shortened, accounting for the inverse pattern of vowel nasalization and N-duration. However, a question is still left unanswered as to why English showed an increase in both N-duration and vowel nasalization in CVN#. While we do not have a conclusive account to offer, it may be that the magnitude of the velum lowering gesture is relatively larger in English, and possibly further expanded IP-finally, so that its effect is stretched bi-directionally over the vowel and the following consonant. In addition, or alternatively, languages may employ differential intergestural timings between the oral and the velic gestures, resulting in cross-linguistic variation just as languages employ differential intergestural timings between the oral release gesture and the glottal adduction gesture, which accounts for cross-linguistic variation in VOT (Cho and Ladefoged, 1999).

Finally, cross-linguistic similarities and differences can be discussed in terms of phonetic realization of the domain-initial N and the vowel nasalization in #NVC. Korean showed a shortening of N in #NVC, as has also been found in English. This is consistent with the view that the domain-initial strengthening effect on N increases its [consonantal] feature, enhancing the syntagmatic CV contrast (Fougeron and Keating, 1997).

However, the two languages stood in sharp contrast in the way that the following vowel was nasalized. While English showed a phonetic proximity effect, i.e., vowel nasalization was larger near N in #NVC, Korean showed the opposite effect, i.e., the nasality of the vowel was most extremely reduced at the measurement point most proximal to N with a gradual increase after that. Again, the lack of the phonetic proximity effect on #NVC can be attributed to the denasalization process of N in Korean, and hence no coarticulatory influence on the following vowel. The gradual increase of the nasality in both #NVC and #CVC, as indicated by additional ANOVA tests with Consonant, could then be interpreted as a by-product of the natural velic declination that tends to occur over the course of an utterance or even within a syllable regardless of whether oral vs nasal segments are involved (Krakow, 1993). This, however, does not mean that the [nasal] feature is completely delinked, as reflected in the presence of nasal murmur during N, (though reduced) as well as the maintenance of the vowel nasality difference between NVC and CVC in the early part of the vowel. As suggested by a reviewer, this may be interpretable as suggesting that the velum lowering gesture in NVC is aligned later, accounting for the denasalization process in Korean. To the extent this possibility holds, the vowel nasalization process in both CVN and NVC in Korean may be differentiated from that in English, in that the velum lowering gesture in Korean is aligned earlier with the oral gesture in CVN, but later in NVC than that in English.

In conclusion, the current study demonstrated that prosodic prominence and boundary differentially influence the degree of coarticulatory vowel nasalization in CVN# and #NVC in Korean, along with some evidence for mutual interactions of prominence and boundary in the phonetics-prosody interface. The comparison between the current results and those of English provides further evidence that the detailed phonetic manifestation of the seemingly low-level coarticulatory process may be further controllable by the speaker, and that the phonetics-prosodic interface surfaces with a phonetic fine-tuning, albeit based on phonetic underpinnings, in reference to language-specific features at various levels, resulting in cross-linguistic variation.

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References and links

Beddor, P. S. (**2009**). "A coarticulatory path to sound change," Language **85**(4), 785–821.

Beddor, P. S., Harnsberger, J. D., and Lindemann, S. (**2002**). "Language-specific patterns of vowel-to-vowel coarticulation: Acoustic structures and their perceptual correlates," J. Phonetics **30**, 591–627.

Chen, M. (**1996**). "Acoustic correlates of nasality in speech," Ph.D. dissertation, Massachusetts Institute of Technology.

Cho, T. (**2016**). "Prosodic boundary strengthening in the phonetics—Prosody interface," Lang. Ling. Compass **10**(3), 120–141.

Cho, T., Kim, D., and Kim, S. (**2017**). "Prosodically-conditioned fine-tuning of coarticulatory vowel nasalization in English," J. Phonetics **64**, 71–89.

Cho, T., and Ladefoged, P. (**1999**). "Variation and universals in VOT: Evidence from 18 languages," J. Phonetics **27**, 207–229.

Fougeron, C., and Keating, P. A. (**1997**). "Articulatory strengthening at edges of prosodic domains," J. Acoust. Soc. Am. **101**(6), 3728–3740 (1997).

Garellek, M., Ritchart, A., and Kuang, J. (**2016**). "Breathy voicing during nasality: A cross-linguistic study," J. Phonetics **59**, 110–121.

Jun, S. A. (**2005**). "Prosodic typology," in *Prosodic Typology: The Phonology of Intonation and Phrasing*, edited by Sun-Ah Jun (Oxford University Press, New York), pp. 430–458.

Keating, P. A., Cho, T., Fougeron, C., and Hsu, C. (**2003**). "Domain-initial strengthening in four languages," Papers in Laboratory Phonology VI: Phonetic Interpretations, pp. 145–163.

Kim, Y. (**2011**). "An acoustic, aerodynamic and perceptual investigation of word-initial denasalization in Korean," Ph.D. dissertation, University College London.

Krakow, R. A. (**1993**). "Nonsegmental influences in velum movement patterns: Syllables, sentences, stress, and speaking rate," in *Nasals, Nasalization, and the Velum*, edited by M. Huffman and R. A. Krakow (Academic Press, New York), pp. 78–116.

Kühnert, B., and Nolan, F. (**1999**). "The origin of coarticulation," in *Coarticulation: Theory, Data and Techniques*, edited by W. J. Hardcastle and N. Newlett (Cambridge University Press, Cambridge), pp. 7–30.

Mücke, D., and Grice, M. (**2014**). "The effect of focus marking on supralaryngeal articulation—Is it mediated by accentuation?," J. Phonetics **44**, 47–61.

Scarborough, R., Zellou, G., Mirzayan, A., and Rood, D. S. (**2015**). "Phonetic and phonological patterns of nasality in Lakota vowels," J. Int. Phonetic Assoc. **45**(3), 289–309.

Yoshida, K. (**2008**). "Phonetic implementation of Korean denasalization and its variation related to prosody," IULC Working Papers **8**(1).

Zellou, G. (**2017**). "Individual differences in the production of nasal coarticulation and perceptual compensation," J. Phonetics **61**, 13–29.