Phonetic implementation of Korean "denasalization" and its variation related to prosody

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Abstract This paper reports the results of a phonetic experiment investigating Korean 'denasalization', specifically, on the amount of nasality as a function of different prosodic contexts. The variation in nasal energy of onset nasal consonants of 5 subjects, from regions where the tendency of 'denasalization' is reported to be strong (Kyunggi-do: 3 subjects) and weak (Kyungsang-do: 2 subjects) were examined. The results reveal that Korean 'denasalization' is incomplete and that nasality weakens as the prosodic boundary becomes stronger. Furthermore, the results uncovered a significant difference between two dialects in this tendency; nasal weakening is stronger in Kyunggi-Do dialects. The degree of nasality weakening as a correlate of segmental duration was also examined. The results show different patterns for the two dialects. The Kyungsang-Do speakers show (at least partially) duration-dependent variation of nasality; the longer the nasal relative to the tautosyllabic vowel, the weaker the nasality gets. In contrast, stratification of nasality, independent of the durational factor is observed for the Kyunggi-Do speakers. This suggests a different status of nasal weakening for the two dialects.

1. Introduction

1.1. Purpose

The purpose of this paper is to report on the phonetic implementation of Korean 'denasalization' and examine its cause, focusing on the prosodic conditioning of the phenomenon. 'Denasalization' refers to a phonetic fact about Korean onset nasal consonants where nasal consonants, /m/ and /n/, loose its nasality, especially in their offsets and are heard as [mb] and [nd]. Korean has three contrastive nasals /m/, /n/, and /ŋ/. Only /m/ and /n/ are discussed here since /ŋ/ appears only in coda position. It has long been recognized that these two nasals weaken or lose nasality in onset position. Figure 1 shows a typical example. The nasal murmur gets weaker during the consonantal closure and the consonantal release resembles a non-nasal plosive, with a light spike-like energy transient. Umeda's (1957) transcriptions of these sounds, are [mb] and [nd], suggesting cessation of the nasal sound towards the end of the segment, leading to a sound akin to ‘partially nasalized consonant’ by the definition of Ladefoged and Maddieson (1996) or ‘prenasalized stop’ by Burton et. al (1992).

Figure1 : An example waveform and broadband spectrogram of 'denasalization' in a part of a rendition of the sentence number 9 '[i **nul**limte] (pilljɔ dʑusejo)] (Please let me use this spool)' by speaker #1. The portion of the target nasal consonant /n/ is highlighted with a rectangular window.

"Denasalized nasals" do not contrast with (fully nasalized) nasals, and thus are allophonic in Korean. Therefore, they generally escape awareness of native speakers/listeners and sometimes appear in their L2 pronunciation (e.g., in Japanese, Sukegawa 1993). When denasalization appears in their L2 sound, however, non-native listeners sometimes perceive them as voiced plosives, /b/ and /d/ (Takeysu 2004). It has also been known that the strength of this phenomenon varies by dialect (Umeda 1989); generally the further north in the Korean peninsula, the stronger this denasalization becomes.

A past study (Yoshida 1998) examined the relationship between denasalization and strength of syntactic boundary. However, as equipment reliable for nasality measurement was not available, nasal consonant data were simply dichotomized as 'denazalized' or 'not' by auditory impression, and the 'degree' of denasalization could not be quantified. Because of this methodological limitation, further scrutiny of the influence of the various conditioning factors could not be made. This paper is a follow-up report which discusses an experiment that tried to overcome this shortcoming.

1.2. Background

This section summarizes previous results and introduces the issues to be pursued in the present study. The first issue is the "existence of *sub-phonemic categories*" in Korean nasal consonants; that is, whether the difference between a normal nasal and a denasalized nasal is phonetically discrete. Takeyasu (2004: 2) classifies the phonetic variants into three types: *ordinary nasal*, a sound similar to a *(nonnasal) voiced plosive*, and a sound similar to (*nonnasal) voiceless plosive*. Takeyasu's classification seems to be based on the observation of nasal murmur in spectrograms. He argues that the consonants become non-nasal when no murmur can be observed in the consonant portion. However, since no analysis was given and spectrograms may not show sounds with very low intensities, it is unclear whether nasality is really absent and that discrete phonetic categories can really be established.

The second issue is the "*cause*" of denasalization, i.e., whether 'denasalization' is the outcome of directed articulatory control, or an automatic by-product of some higher-level planning of speech production, such as prosody. Yoshida (1998) examined the relationship between segmental duration and denasalization. The duration of onset nasal consonant /m/ and following tautosyllabic vowel /u/ were compared, relating to whether this nasal consonant is perceived as 'denasalized'. A statistically significant tendency was found that denasalized consonant tokens have a longer duration than full-nasal tokens. It is important that duration of the following vowel does not become significantly longer. This suggests that there may be a durational 'adjustment' to make the consonant portion sufficiently long to reserve time to achieve denasalization during the closure. But since there was no measure of strength of nasalization available, the direct relationship of durational adjustment and the degree of denasalization could not be examined.

The third issue pertains to the "*motivation*" of denasalization, i.e, the question of why Korean nasals are to be realized with less nasality in certain conditions. Cho and colleagues' series of researches on 'domain-initial strengthening' have important bearing on the current issue (Cho and Keating 2001, Cho and Jun 2000, among others). "Strengthening" refers to the phonetic fact that consonants are pronounced with longer and stronger closures in the initial position of certain prosodic domains; the effect is "the stronger the prosodic boundary, the more extreme the articulatory gesture, possibly nearer to the consonant target" (Cho and Keating 2001:178). Korean nasal /n/ was examined in their study along with alveolar plosives /t/, /t^h/ and /$t^ʔ$/. Cho & Jun argue that weakening of nasality has a perceptual merit with ‘low sonority and more consonant-ness' (Cho and Jun 2000: 2) The result of this study does not address to this issue directly. However, I will briefly discuss the implication of the current result in the last section.

2. Procedure

2.1. Experimental design and test sentences

The five prosodic conditions in (1) are examined to observe the variation of nasality as a function of the strength of the prosodic boundary. The conditions are not strictly prosodic but are syntactic/morphemic. Target nasal consonants are all in syllable initial position and appear in five different syntactic conditions from 'Utterance initial' (strongest boundary) to 'Syllable initial' (weakest boundary). The terms for prosodic category in (1) and its concept concerning the prosodic structure are largely based on Jun (1996), in which prosodic catetories, such as AP, IP are defined as domains of phonological phenomena such as Lenis Stop Voicing, phrasal accent, phrase final intonation, and so on. This prosodic model assumes that mismatches between prosody and the phrasal domain defined by syntactic structure pervasively exist. Therefore, the names of five phonological conditions should be regarded as labeling criteria for relative boundary strength. Jun’s prosodic model has been developed further by several researchers (Jun 1998 Jun 2004, Mimatsu & Utsugi 2002, Utsugi 2003a, 2003b etc.). Yet since this seems to be the most comprehensive current model of Korean prosody, the discussion here is based largely on Jun’s model.

(1) Prosodic contexts for the production experiment

a) U (Utterance initial)
b) IP (Intonational Phrase initial) Initial position of a clause inside a sentence, after a brief pause.
c) AP (Accentual Phrase initial) Initial position of a verb phrase, just after a subject noun phrase.
d) Wd (Word initial) Inside a noun phrase, initial position of the noun in ‘A+N’ construction.
e) Syl (Syllable initial) Syllable onset position inside a prosodic word.

Condition (1e) is expected to be the one where denasalization does not occur. Among 40 tokens with the similar construction in Yoshida (1998), no denasalization was observed for this condition. On the other hand Conditions (1a)-(1c) are the typical environments where we observe denasalization in the previous studies. Target nasals /m/ and /n/ were located in the context /i_ul/ as far as it is possible. The tautosyllabic vowel was chosen to be /u/ because denasalization is more likely to occur before high vowels (Umeda 1957, Yoshida 1995, 1998). To achieve these experimental conditions, the test sentences in (2) were created. Yoo-Kyung Shin (speaker S1) helped improve the sentences so that native speakers could pronounce them more naturally. Some infrequent words and expressions were replaced, and pragmatic unnaturalness was corrected through this revision.

(2) List of test sentences (with broad IPA transcriptions, glosses and English translations)

Target consonant: /m/

1) U [**mu**li issˀmnikkˀa]
Water-nom. have-Decl.
'Do you have water?'

2) IP [abɔdʑi **mu**li maɕiᵗˀsɯmnikkˀa]
Father, water-Nom. taste-good-Decl.
'Papa, do you find the water taste good?'

3) AP [igɔɕi **mu**limnikkˀa]
this-thing-Nom. water-Decl-Q
'Is this water?'

4) Wd [i **mu**lɯn maɕiᵗˀsɯmnikkˀa]
this water-Top. taste-good-Decl.-Q
'Does this water taste good?'

5) Syl [kɯ saramɯn ɕi**mu**rukʰesɔ mariɔptʰa]
that person-top. bitterly word-nom.
not-have-Decl.
'This man keeps silent bitterly.'

Target consonant: /n/

6) U [**nu**lljɔ tɕinesɔ pigonhettʰa]
being-depressed live tired-Past-Decl.
'I felt tired from living depressed.'

7) IP
[tɕal moᵗˀen dʑɔmi isˀɔdo **nu**llɔ pwa dʑuɕio]
poorly-done thing-Nom. happen-even
generously see Desiderative
'Please forgive me generously if there are something I don't do well.'

8) AP [perɯl **nu**llɔ polljɔtˀta]
bell-Acc. push finish-Past-Decl.
'I (mistakenly) pushed the doorbell!'

9) Wd [i **nu**llimte pilljɔ dʑusejo]
this spool lend Desiderative
'Please let me use this spool.'

10) Syl [kɯ saramɯn pi**nu**ro sonɯl ɕiᵗˀko iᵗˀta]
that person-top. soap-with hand-Acc. wash
progr.-Decl.
'This man is washing his hands with soap.'

2.2. Speakers

Five female native speakers of Korean participated in the production experiment. Demographic information is given in (3)[1]. The speakers S1-S3 are from Seoul and its surrounding cities. K1 and K2 are from Kyungang-Do dialect area. All speakers learned Japanese for several years and thus are quite proficient in the language. Yoshida (1995, 1998) shows, however, that denasalization can be observed independent of speaker's fluency in Japanese.

The speakers read the test sentences displayed on PC screen. The sentences were randomized in

[1] Another female speaker was recorded. However, her data was not examined since she had moved from Kyungsang-Do to Seoul when she was 10 years old and thus it is unclear which dialect she represents.

different orders for each repetition of the list. Speakers read the list 5-7 times so that at least 5 repetitions per speaker could be obtained. The only instruction given to speakers was to read the sentences at a comfortable pace. Therefore, the speech rate varied from speaker to speaker considerably. All the speech samples were analyzed except for the sessions where recording levels were clearly weaker than the other sessions of the same speaker. In consequence, we obtained 310 tokens (5 speakers, 10 test sentences, 5-7 repetitions, see Table 1 for detail).

(3) Subjects of production experiments

	Born	City	Relocation	Learn Japanese
S1	1969	Seoul	None	3 years
S2	1976	Seoul	Temporarily lived in Wonju, Kangwon-Do at 7 years old	3
S3	1978	Anyang	Born in Daejeon, moved in Anyang at 4 years old	6
K1	1973	KyungJu	Lived in Seoul from 24 to 28 years old	10
K2	1980	Busan	None	5

2.3. Recordings

The speech samples were recorded in June 2004 and January 2005, at the Speech Laboratory of School of Humanity, Tamagawa University, Machida, Japan, using a Nasometer 2, Model 6400 by Kay Elemetrics Corp. This is a clinical speech device for recording oral and nasal sound separately with two microphones attached to both upper and lower sides of a plastic board. This board is put between nose and mouth of speakers with the seal of gum tube so that oral and nasal sounds do not interfere with each other. The two speech sounds are recorded as one digital sound file with two separate but time-synchronous channels, which enables the both sounds to be analyzed in parallel. The recordings were made with 16-bit quantization and a sampling rate of 11.025 KHz. Nasometer has this fixed sampling rate optimal for pathological diagnosis of nasality and thus do not capture the component in higher frequency regions, e.g., frication noise. This is sufficient and ideal for analyzing nasal sound whose primary component is in lower frequency region.

3. Acoustic characteristics and measurements

3.1 Three profiles of nasality

As a first approximation, this section investigates acoustic characteristics of the 'denasalized' nasality in Korean nasal consonants. From the inspection of the sound wave and the intensity display of the nasal channel, the profiles of nasality in Korean onset nasal consonants fall into one of the three categories.

Falling nasality: The first is the case where the nasal sound becomes weaker toward the end of the nasal consonant interval as in Figure 2a. This pattern will be called '*falling nasality*' below. The nasal sound reaches its minimum at around the boundary between nasal and vowel. This type is observed the most frequently and when its minimum nasal energy is low enough, the consonant is perceived as 'denasalized'. This is presumably the typical case of 'denasalized' nasal.

Flat nasality: The second is the case where no nasal weakening is observed, as in Figure 2b. Nasality is kept around its maximum during the whole nasal interval. We will call this pattern '*flat nasality*'. This type can be considered as typical case of fully-nasalized (non-denasalized) nasal. There are cases, however, where nasality is near to its full magnitude in the beginning and becomes weak toward the end. It seems that the difference between the first and the second cases may not be an absolute one but the two may form a continuum. This issue will be discussed in section 4 and 5.

Rising nasality: The third case is where a nasal sound becomes stronger toward the end of the nasal consonant portion as in Figure 2c. We will call this pattern '*rising nasality*'. This is typically observed when there is a pause before the nasal (U and some IP). Nasal (as well as oral) sound ceases during the pause, then nasal sound starts again and grows toward the end of the nasal interval. Therefore nasality is not in its minimum at the end, unlike other two cases. This may arise due to insufficient time for the nasal energy to reach to its local target. There are, however, some cases where the nasal reaches its local maximum, and then nasal sound starts to decrease even in the prosodic condition U and IP. In this case, the same pattern of nasality contour as the *falling nasality* pattern was observed after the initial rise in nasality

The three patterns are tentatively proposed for convenience of analysis and discussion. However, the classification will be in part supported by the patterns of variation in nasality. This will be discussed in section 5.

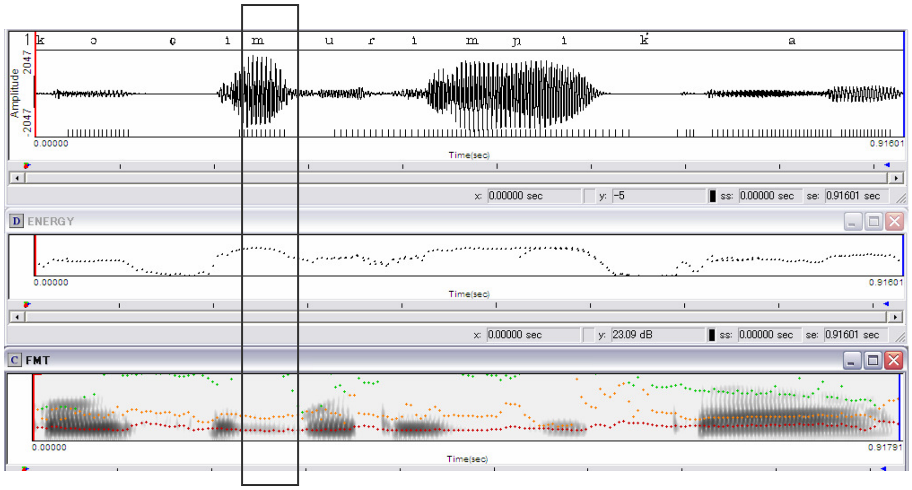

Figure 2a: An example of *falling nasality* (speaker S4, sentence 3). The top panel shows the nasal sound wave with broad IPA transcription ; the middle, dB SPL energy contour of nasal sound; the bottom, broad band spectrogram of oral sound with formants overlaid on it. The target nasal consonant /m/ is highlighted with a rectangular.

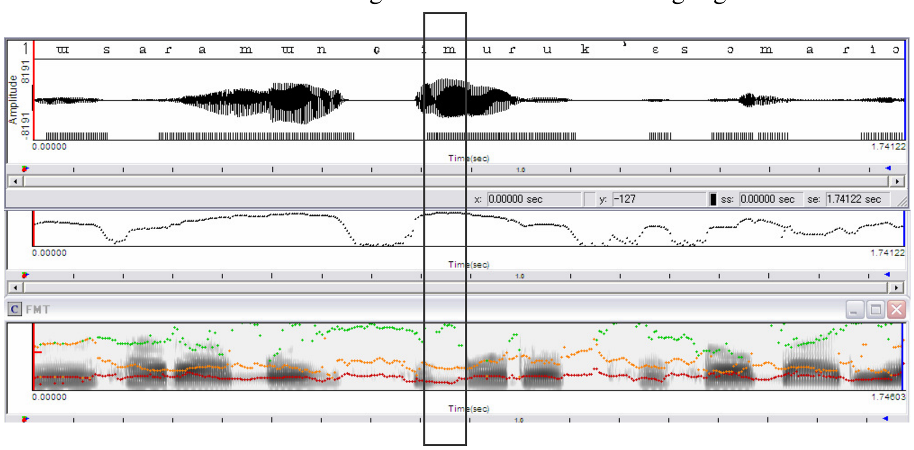

Figure 2b: An example of *flat nasality* (speaker S1, sentence 5).

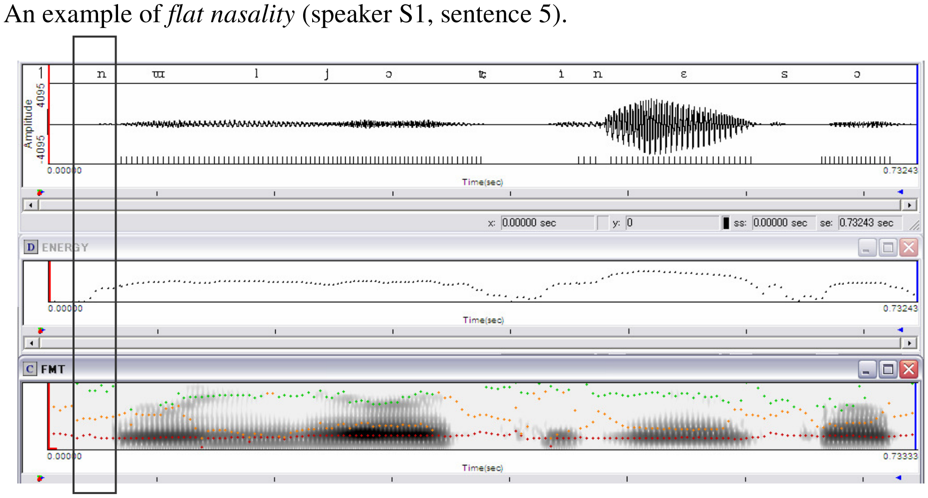

Figure 2c: An example of *rising nasality* (speaker S4, sentence 6).

3.2 Acoustic measurements

Based on the previous discussion, *nasal energy at the end of the nasal interval* (in dB SPL) will be used as the index of strength of nasality for following analysis. This is because the main interest here is the extent to which nasality is weakened and how much Korean nasals consonants become similar to non-nasal plosives, especially at around the transition from nasal consonant to the following vowel where important perceptual cues are supposed to be included. Also, the observation in previous section reveals that the nasal sound minimum is in most cases observed at the end of the nasal consonant.

Acoustic measurements were made using Multispeech Signal Analysis Workstation 3700[2]. Four acoustic values listed in (4) were measured. Segmental duration was determined with reference to sound wave and broadband spectrogram display[3]. dB SPL nasal energy was calculated pitch-synchronously using 30ms analysis window.

(4) Acoustic values measured

- (a) Duration of the target consonant /m//n/ (sec.)
- (b) Duration of the following (tautosyllabic) vowel (sec.)
- (c) dB SPL power of nasal channel at the end of the interval of the target nasal consonant : *Nmin*
- (d) Maximum dB SPL power of nasal channel in a test sentence other than (c) (dB) : *Nmax*

The ratio of (4a) and (4b) was calculated and will hereafter be called *N/V rate*. This value will be used as an index of timing control discussed in section 1.2, i.e., whether only the nasal portion is lengthened rather than the target syllable as a whole, which potentially works for reserving enough time for implementing denasalization.

The dB SPL energy depends on the individual recording condition, e.g., volume difference between speakers and the distance from mouth to microphone. Therefore this value may not be consistent across speakers. Maximum dB SPL energy during the sentence other than the target nasal (4c) was measured as an index of the differences between speakers (or between recording sessions). Differences in this measure between speakers was quite large (64.9(S1) ~ 58.4(K1)). Therefore, it appears appropriate to use this measure to normalize the inter-speaker differences when making comparison of the degree of denasalization between speakers. This is done in section 4.1.

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[2] This speech analysis tool is a product of Kay Elemetrics with the same specifications as those of Kay CSL 4300B.

[3] For the data with /l/ in coda position, duration measurements were difficult in some cases. Sudden decrease of amplitude usually observed in sound wave and spectrogram was used as the indication of the boundary between preceding vowel and /l/. However, it is expected that the reliability of duration measurement is worse than other conditions.

4. Results

4.1 General result: Consonant × Prosodic context × Dialect

This section discusses the general results of the acoustic measurements. First, to examine the effect of consonant, prosodic context, and speaker, a 3-way ANOVA was carried out on the whole set of measurements. The dependent variable is *Nmin* value normalized by *Nmax*. This normalization was done to normalize speaker-specific nasality level (see section 3.2). As dB SPL energy is in logarithmic scale, the ratio between the two measures was obtained by subtracting the one from the other. This derived measure (*Nmax* – *Nmin*) will hereafter be called *Nnorm* (normalized *Nmin*). The independent variables are Consonant (/m/, /n/), Prosodic context (U, IP, AP, Wd and Syl) and Speaker. Speaker was treated as a random factor. The result revealed significant main effects for Prosody ($F(4, 16.1) = 26.41$, $p < .000001$) and Speakers ($F(4, 10.0) = 7.67$, $p < .005$). Significant interactions of Consonant × Prosody ($F(4, 16.3) = 5.44$, $p < .01$) and Prosody × Speakers ($F(16, 16) = 3.09$, $p < .05$) were also found. The main effect of consonant did not reach to significance ($F(1, 4.1) = 4.07$, $p = .112$).

Because the significant Speaker effect (both main effects and an interaction) was found, it seems appropriate to incorporate it in the analysis design, not simply treating it as a random factor. In order to do this, another 3-way ANOVA with a slightly different design was carried out on the same data set. The dependent variable is again *Nnorm*. In addition to Consonant and Prosodic context factors, Dialect (Kyunggi-Do and Kyungsang-Do) was added as another non-random factor, replacing Speaker as a random factor. Our discussion will be based on the result given by this second ANOVA. The result is given in Table 1, and the mean dB SPL values as a function of Consonant and Prosodic context are given in Figure 3 in the next page. Note that *Nnorm* is mostly negative, since this is given as the difference between *Nmax* and *Nmin*, or the magnitude of nasality weakening relative to reference maximum nasality in the same sentence.

The result revealed a significant main effect for all three independent variables. First, although the main effect of Consonant was significant ($\alpha = .05$), it has a very small effect size. A significant Consonant × Prosodic interaction was also found. As can be seen from the Figure 3, this is due to the crossover in AP condition. Apart from this crossover, the general trend is that /n/ is stronger in nasal weakening[4]. This crossover is presumably due to the differences between the two test sentences in the AP condition with /m/ and /n/ as the target consonants. The target consonant is after a phrase ended with Nominative particle for the test sentence of /m/ while it is after a phrase ended with Accusative for the one of /n/, which might function as a contaminating factor.

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[4] This general trend conforms to Umeda's (1958) observation that denasalization is more frequently observed for /n/ than for /m/.

Table 1: Result of 3-way ANOVA of normalized nasal minimum (*Nnorm*); with Consonants (/m/ and /n/), Prosody (U, IP, AP, Wd and Syl) and Dialect (Kyunggi-Do and Kyungsang-Do) as independent variables. A measure of effect size (η^2) is also shown. Significant effects are highlighted in bold letters.

Source	Type III SS	*df*	*MS*	*F*	*p*	η^2
Intercept	67408.0	1	67408.0	1566.14	0.000	0.844
Consonant	**188.7**	**1**	**188.7**	**4.38**	**0.037**	**0.015**
Prosody	**16892.6**	**4**	**4223.2**	**98.12**	**0.000**	**0.575**
Dialect	**3654.7**	**1**	**3654.7**	**84.91**	**0.000**	**0.226**
Consonant * Prosody	**879.5**	**4**	**219.9**	**5.11**	**0.001**	**0.066**
Consonant * Dialect	16.1	1	16.1	0.37	0.542	0.001
Prosody * Dialect	**1435.1**	**4**	**358.8**	**8.34**	**0.000**	**0.103**
Consonant * Prosody * Dialect	377.9	4	94.5	2.20	0.070	0.029
Error	12481.8	290	43.0			
Total	111884.8	310				

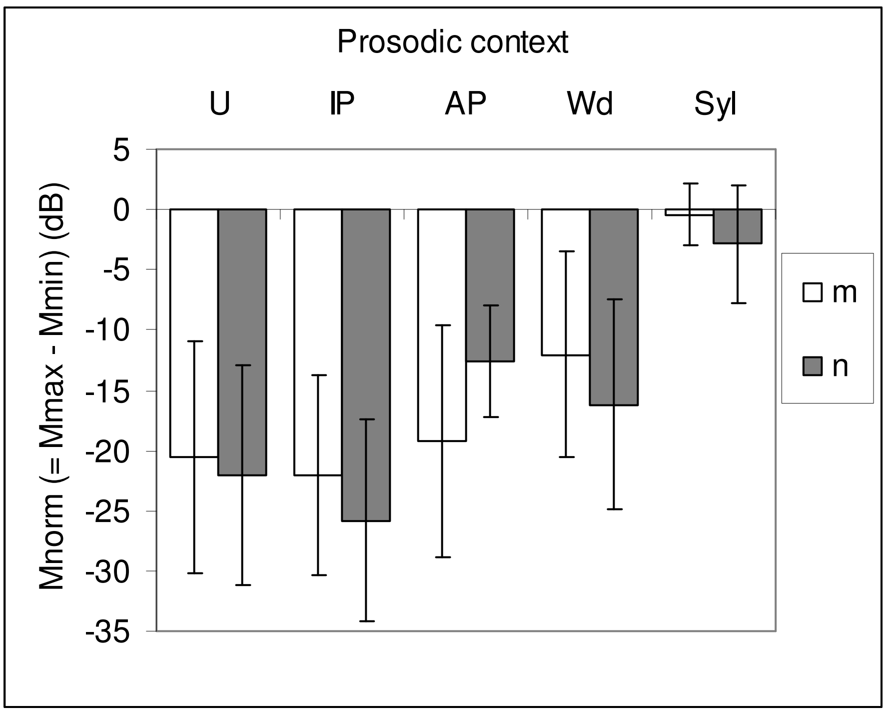


Figure 3: *Mnorm* values as a function of Consonant and Prosodic contexts. Mean *Mnorm* values are shown as bars and standard deviation values are indicated by error bars. Note that *Nnorm* values are mostly in negative value as this is difference between *Nmax* and *Nmin* (see text). The abbreviations are the same as in (2) in the page 5.

Second, a significant main effect of Prosody was found, with by far the largest effect size. This effect will be further examined below. Finally, a significant main effect of Dialect is also found, with an intermediate effect size. The trend is that nasality is weaker in Kyunggi-Do than Kyungsang-Do speakers (mean of overall *Nnorm*: –18.42 vs. –11.46 dB). A significant interaction of Prosodic context × Dialect is also found, with a small effect size. This speaker-specific difference will be discussed in section 4.3.

4.2 Prosodic context effect

This section examines the effect of Prosodic context in more detail. A post-hoc test of multiple comparisons was conducted to see which Prosodic contexts cause significant difference in nasality. As the condition of homogeneity of variances was found violated (Levene's test of equality of variances: $F(19, 290) = 4.23$, $p < 0.000001$), Dennett T3 test was carried out, along with Tukey's HSD test (Maxwell and Delaney 2004: 212). In fact, both post-hoc comparisons yielded the same conclusions. All the comparisons between the Prosodic contexts were significant ($p < .005$ or lower) except for U vs. IP ($p = .989$) and AP vs. Wd ($p = .967$) pairs. This confirms that nasality varies as a function of prosodic context. The trend is that the nasality gets weaker corresponding to the boundary before the target nasal consonant becoming stronger. This result replicates the finding of Cho and Keating (2001). Also, the result reveals that there are three categories in the degree of denasalization related to prosodic context – U and IP, AP and Wd, and Syl. Moreover, the three categories largely correspond to three profiles of nasality discussed in the section 3.1. Nasality is weakest in U and IP conditions, where *rising nasality* is typically observed. Nasality is weak in AP and Wd conditions, where *falling nasality* is typically observed. Nasality is strongest in Syl (non-word initial) condition, where full and *flat nasality* is typically observed. This confirms that denasalization is not observed word-internally (Umeda 1958, Yoshida 1998). However, total cessation of the nasal sound was not observed in the data set of this experiment. Although nasal sound decreases toward the boundary between the nasal and the following vowel, it does not cease completely. Therefore, as far as the experimental condition of this study is concerned, so called denasalization is better be described as *weakening* of the nasal sound. According to the classification by Maddieson and Ladefoged (1993: 281), this seems similar not to ‘partially-nasal consonant’ but to 'orally-released nasal' which is, according to their description, '*realizing nasal with weak nasal sound at its closure release*', presumably with less lowering of velum and weaker nasal sound. Based on this observation, I will use a term *nasality weakening* in the following discussion in place of *denasalization* to refer to the phonetic phenomenon we observe in Korean.

4.3 Dialectal differences

Next, the difference in nasal weakening between Kyunggi-Do and Kyungsang-Do speakers should be examined in more detail. To do this, 2-way ANOVAs were conducted for 5 speakers separately, which is summarized in Table 2. The dependent variable is *Nnorm* and independent variables are Consonant and Prosodic contexts. To examine which prosodic context causes a significant difference in nasality, post-hoc multiple comparisons are also carried out. As the condition of homogeneity of variances was found violated for 4 out of 5 speakers, the result will be reported based on Dennett's T3 test.

Table 2: Result of 2-way ANOVA performed separately for individual speakers. The *p*-values for significant results (α = .05) are shown. For multiple comparisons, equal sign (=) indicates the difference is not significant between the adjacent pair, while less-than sign (<) indicates the difference is significant (based on Dennett's T3 test).

		Main effects		Interaction	Multiple comparisons
Speakers	N	Consonant	Prosody	Cons × Pros	
S1	50	n.s	$p < .0001$	n.s	U = IP = AP = Wd < Syl
S2	70	n.s	$p < .0001$	$p < .005$	IP < U = AP = Wd < Syl
S3	60	n.s	$p < .0001$	$p < .001$	U = IP = Wd < AP <Syl
K1	60	n.s	$p < .0001$	n.s	IP = U < AP = Wd < Syl
K2	70	$p < .01$	$p < .0001$	n.s	IP = U < AP = Wd < Syl

The result reveals a significant main effect of Prosodic context for all the speakers. A significant main effect of Consonant is found only for one speaker. A significant interaction of Consonant × Prosodic context was found for two speakers. The trend of mean nasality reveals that this is due to a 'crossover' discussed in section 4.1 (Figure 3). This again confirms that prosodic context alone explains by far more variance in the data. Multiple comparisons reveal that nasality is higher for Syl condition than all others for all the subjects. Apart from this, for Kyungsang-Do speakers (K1, K2), significant differences are found between IP, U and AP, Wd. This suggests that for Kyungsang-Do speakers, nasality weakening has two gradual steps, corresponding to the strength of prosodic boundaries (U, IP / AP, Wd / Syl). For Kyunggi-Do speakers (S1 – S3), significant differences are found only sporadically and inconsistently. This suggests that for Kyunggi-Do speakers, nasality weakening is a single step which is larger than that of Kyungsang-Do speakers, to the extent that those tokens above word level (U, IP, AP and Wd) may invoke mis-categorizations of Korean nasal consonants as oral plosives by non-native speakers (i.e, denasalization). This can be visually confirmed by Figure 4, which shows mean *Nnorm* values as a function of Prosodic context and Speakers. This may explain the observations of previous studies that 'denasalization' is more frequently observed in northern dialects.

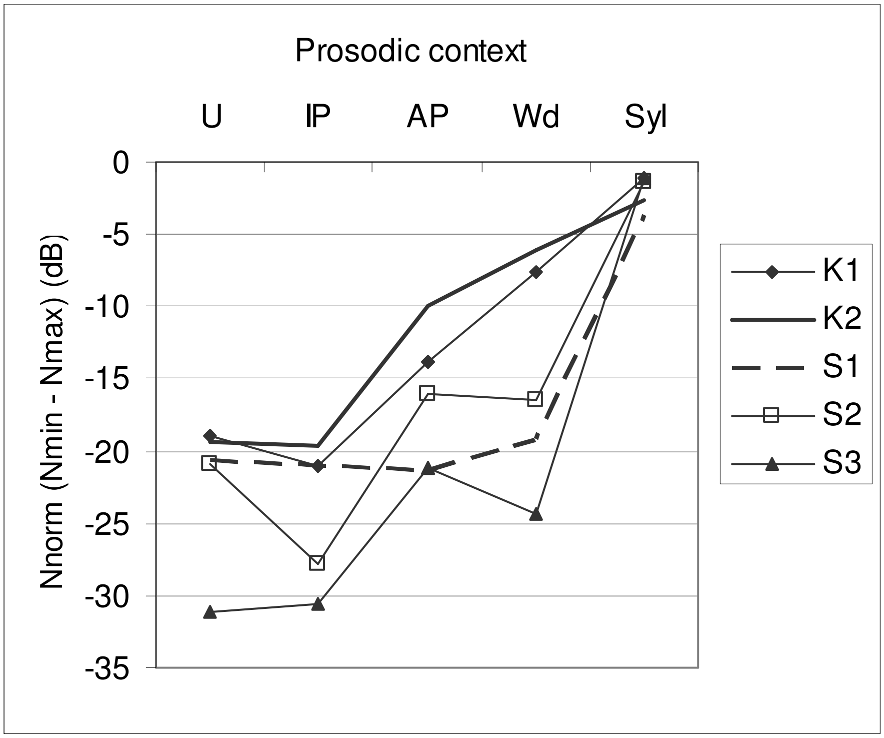


Figure 4: Mean *Nnorm* values as a function of Prosodic context and Speakers. Note as in Figure 3 that *Nnorm* values are mostly in negative value as this is difference between *Nmax* and *Nmin* (see text).

4.4 Correlation between nasal sound and segmental duration

This section explores the issue of whether this nasal weakening can be explained as a by-product of a higher-level execution in speech production – segmental duration in the present case. As a large difference in speech rate was observed between speakers, the temporal relationship between the nasal and vowel (*N/V rate*) is used as an index of speakers' timing control of the speaker, instead of absolute duration. The five panels of Figure 5 show scatterplots of *Nmin* as a function of *N/V rate* for each speaker. An *N/V rate* larger than 1.0 means that duration of nasal consonant is longer relative to the following vowel. Each data point represents the individual data and indicated by the first letter of the Prosodic contexts (U, IP, AP, Wd and Syl). Upper case letters are for the date of /m/ and lower case letters are for /n/.

No clear linear correlation can be observed between duration (*N/V rate*) and nasal weakening (*N min*), although tokens of respective prosodic conditions tend to form their own clusters. However, when we take into account the different behaviors between token clusters, a difference emerges between two dialect groups. For Kyungsang-Do speakers, data tokens of the Utterance condition (/m/ for both K1 and K2 and /n/ for K1) have very small *N/V rate*, so short as it reaches to the limit of smallest *N/V rate*. This is because they show the pattern classified as '*rising nasality*' in section 3.1. On the other hand, tokens of

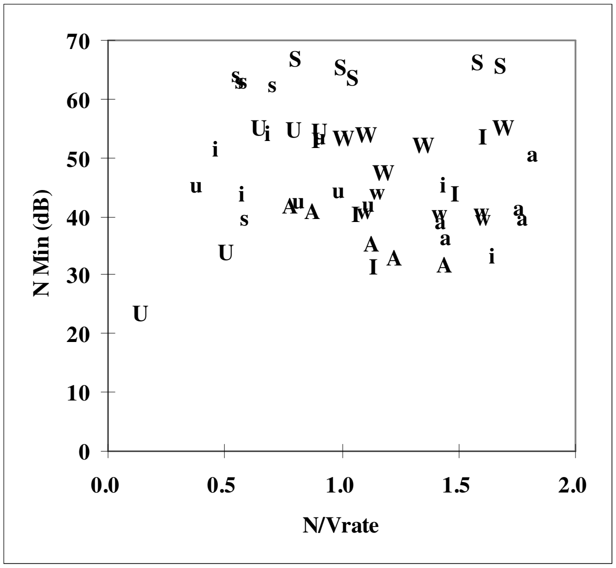
Syllable conditions /m/ (S and s) for K1 have large nasality irrespective of the *N/V rate* as it reaches to the limit of largest nasality for the speaker. They show the *flat nasality* pattern. If we eliminate these cases hitting the 'ceiling', a pattern of correlation between timing and nasality emerges, that is, the longer the N/V rate, the larger the nasality (*Nmin*).

By contrast, for Kyunggi-Do speakers (S1 – S3), the same kind of correlation for the part of the data tokens is not observed. Tokens of Syllable conditions form separate clusters, in the upper 'ceiling' of maximum nasality as observed in Kyungsang-Do speakers. However, exclusion of the data of these conditions from analysis does not reveal a pattern of correlation between timing and nasality although the data tend to form clusters depending on the prosodic conditions. Note that this dichotomy (of Syllable condition vs. others) corresponds to the significant difference confirmed by multiple comparisons carried out for individual speakers (section 4.2, Table 2).

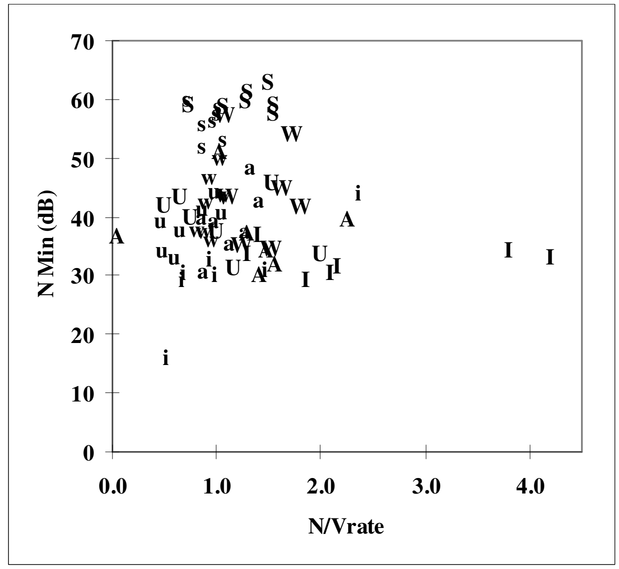
To confirm this observation of dialectal difference in the duration-nasality correlation, linear regression analyses were carried out for the five spakers separately. The predictor is *N/V rate* and the predicted variable is *Nmin*. Nnorm was not used for this analysis because we do not make any between-speaker comparison and this makes more straightforward to interpret the result. The 'ceiling' cases described for Kyugsang-Do speakers in the previous paragraph are excluded from the analysis. In order to make a fair comparison, S and s cases are excluded for Kyunggi-Do speakers. The results are summarized in Table 3. Significant correlations are found only for Kyungsang-Do speakers. This suggests that, when the 'ceiling' cases due to very short nasal duration (corresponding to '*rising nasality*' case) or maximum nasality ('*flat nasality*' case) are excluded, the magnitude of nasality weakening is partially explained by consonant-vowel duration rate for Kyungsang-Do speakers, which may in turn explained by prosodic structure where the target consonants are found. In contrast, for Kyunggi-Do speaker whose denasalization is stronger, nasality weakening cannot be in terms of prosodically induced durational variation.

Table 3: The results of regression analyses conducted for five speakers separately ($Nmin = \alpha + \beta \times N/V\ rate$). Significant results are indicated in bold type. For prosodic conditions excluded, see text.

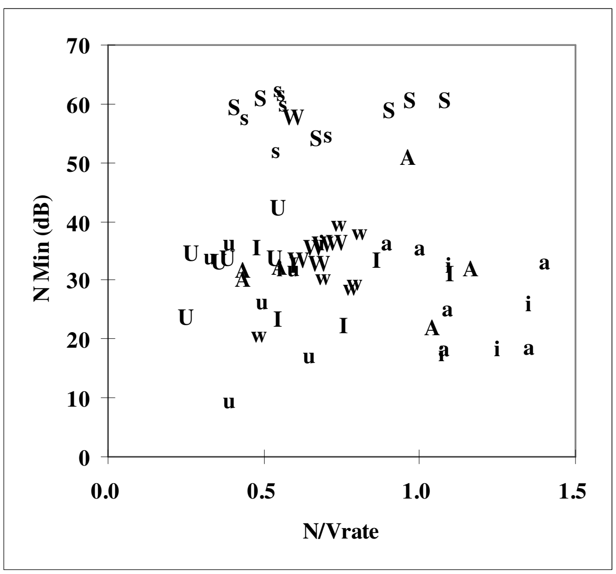
Speaker	N	*r*	β (slope)	*t*	*p*	Prosodic conditions excluded
S1	40	0.030	-0.002	-0.182	0.856	S, s
S2	56	0.05	-0.005	-0.369	0.713	S, s
S3	48	0.168	-4.709	-1.157	0.253	S, s
K1	48	**0.465**	**-5.934**	**-3.563**	**0.001**	U, S
K2	56	**0.302**	**-5.253**	**-2.325**	**0.024**	U, u


N Min (dB)
N/Vrate
0
10
20
30
40
50
60
70
0.0
0.5
1.0
1.5
2.0

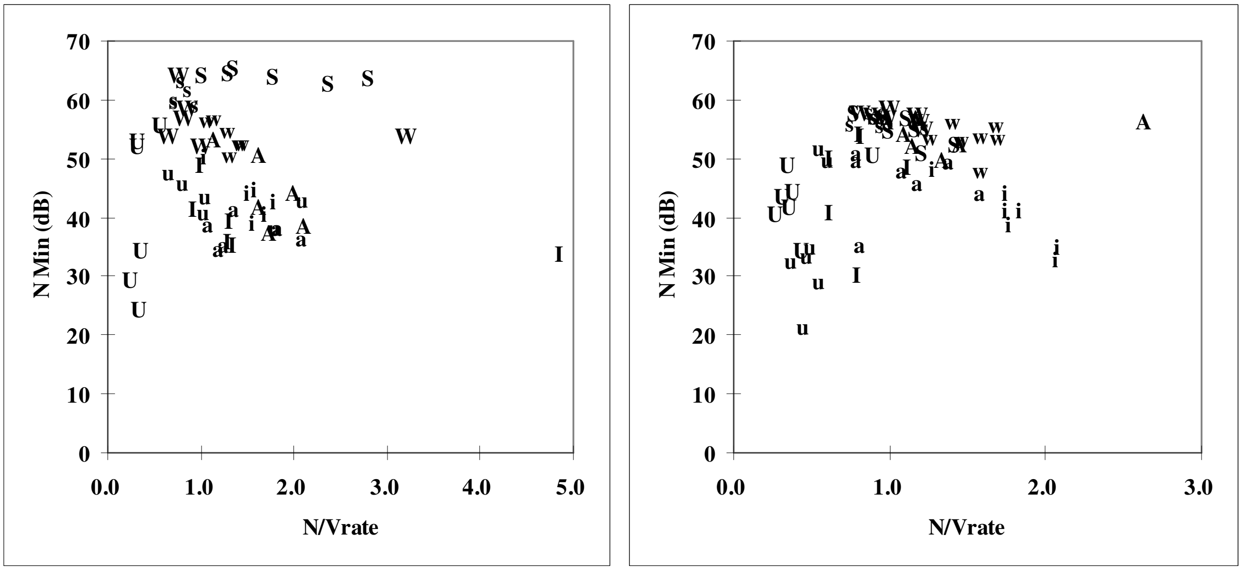
S1


N Min (dB)
N/Vrate
0
10
20
30
40
50
60
70
0.0
1.0
2.0
3.0
4.0

S2


N Min (dB)
N/Vrate
0
10
20
30
40
50
60
70
0.0
0.5
1.0
1.5

S3



K1 K2

Figure 5: Scatter plots of the minimum dB SPL energy of nasal sound (*Nmin*) as a function of the rate of duration between nasal and vowel (N/V rate) for each subject separately. Plotting letters represent the first letter of Prosodic contexts (U, IP, AP, Wd and Syl). Upper case letters are for the cases of /m/ and lower cases are for /n/.

5. Discussion

5.1 Phonetic identity of 'denasalization'

Based upon the results of the present experiment, we will try to answer the three questions posed in section 1.2. As for the issue of the existence of sub-phonemic categories, three patterns of nasality profiles proposed in section 3.1 may be regarded as such a property. In section 4.4, we observed that there are two separate groups of data which have extreme values of relevant measures. One is those with a very short duration of nasal (smallest *N/V rate*) and the other is those with maximum nasality (largest *Nmin*). Those tokens tend to form separate clusters in Figure 5 (S and s for Kyunggi-Do speakers and S and U (u) for Kyungsang-Do speakers). This at least in part supports the existence of three profiles as sub-phonemic categories.

Although this is related to the issue of variation of nasal consonants depending on prosodic context, this is only partly related to nasal weakening. A very small *N/V rate* does not explain small *Nmin* values, as we saw in section 4.4. Moreover, when *Nmin* is actually small for those cases, it is because enough time is not available for nasality to develop, due to very short duration of nasal consonant. In such cases, the nasal consonants are not necessarily perceived as 'denasalized', despite relatively small *Nmin* value. On the other hand, the difference between those cases with maximum *Nmin* values and others may well be regarded as a sub-phonemic category related to nasal weakening. However, as we saw in section 4.4, the token of maximum nasality (mostly S and s) and others do not necessarily form distinct clusters; they rather form a continuum of nasality weakening[5]. This gradience in *Nnorm* value is more apparent for Kyungsang-Do speakers as we can see in Figure 4 and 5, whereas for Kyunggi-Do speakers, a sign of stratification (S,s vs. others) is observed, which is particularly apparent for S1 and S3 in Figure 4 and 5. This may indicate that sub-phonemic categories have emerged for Kyunggi-Do speakers.

The results summarized in this section suggests that the division of Korean nasals into three discreet classes by Takeyasu (2004), i.e., nasal, the sound similar to voiced plosive, and the sound similar to voiceless plosive, needs to be re-examined. It is conceivable that certain distributions of nasal sounds exist as a function of some linguistic/extra-linguistic contexts and these distributions have their discrete phonetic representations e.g., as modeled in Pierrehumbert (2001, 2003). The present study demonstrates that the three profiles of nasality, i.e., *rising/flat/falling nasality* is a possibility, which is only partly related to the degree of denasalization..

5.2 Segmental duration as a conditioning factor of 'denasalization'

This section discusses the second and the third questions put forth in section 1.2, the *cause* and the *motivation* of denasalisation, based on the result reported in section 4.4 i.e., the influence of segmental duration as an underlying factor of determining the degree of nasality weakening.

One of the well studied phonological rules related to prosody in Korean is Lenis Stop Voicing. Jun (1995, 1996) claims that this intervocalic voicing of lenis stops is observed within Accentual Phrase (AP). Jun (1995: 250) also argues that this is a by-product of duration control at the edge of AP and thus is an automatic (i.e., not directly controlled) phenomenon. Regarding denasalization, Yoshida (1998) also found correspondence to syntactic structures (and presumably prosody), which is briefly summarized in section 1.2. Given the time needed for the lowered velum for the nasal to be raised and closed again, there may well be the same kind of relationship between denasalization and the adjustment of segment duration. The study of domain-initial strengthening by Cho and Keating (2001:179) which examined Korean nasal along with other consonants, argues that "initial strengthening arises from effects of prosodic position on segment duration". The results of the present study provide the support for this explanation for Kyungsang-Do speakers, since *Nmin* value varies corresponding to the durational change for the speaker of this dialect. However, this does not apply to the data of Kyunggi-Do dialect speakers, since we found no significant correlation between durational change and nasality.

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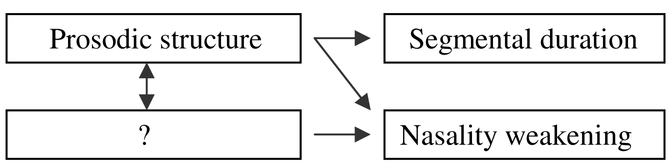
5 Domain initial strengthening, such as nasal weakening, doesn't have to be categorical as Jun & Keating discussed (2000: 158). They claims that initial strengthening "could well be a gradient effect of prosodic position" (p.178).

Two reasons are worth considering. The first is procedural, i.e. the experimental design and measurements. The test sentences of the present experiment are not truly identical across Consonant and Prosodic context conditions. This subtle difference may affect the segmental duration and denasalization independently and contaminate the results. Since duration measurements were made on the acoustic analysis windows (sound wave and spectrogram), it was sometimes difficult to decide the beginning of nasals, especially for U and IP conditions. Cho and Keating (2000) may be more accurate in duration measurements because they measured articulatory seal duration with electropalatography[6]. However, the present data also shows that the durational explanation does not hold even when AP and Wd condition are included for which segmental measurements were straightforward and thus quite reliable. Thus, procedural inadequacy does not seem to be a critical reason for the difference in the dialects.

(5) A model of nasality control for Korean nasal consonants

(a) Kyungsang-Do speakers (for '*Falling nasality*' nasals): duration effect observed

(b) Kyungggi-Do speakers: no duration effect



The second is the possibility that nasality weakening is not an automatic phenomenon depending on the segmental duration, especially for Kyunggi-Do speakers where the effect of duration was not even partly observed. This means that denasalization is not caused through the influence of prosody-driven segmental lengthening/shortening (as in 5a below), but through direct reference to prosodic structures or to some other factors yet to be explored (as in 5b). For Kyunggi-Do speakers, who have stronger nasality weakening, segmental duration and nasal energy vary as functions of prosodic structure, but independently of each other. The two values show apparent correlation (or correspondence) as we see in Figure 3 because

6 In constast, the acoustic energy measure may be more accurate in this study than that of Cho and Keating (2000: 164), where they meausre the RMS amplitude minima during nasal murmur, without separating the acoustic energy from nostril and mouth. This may also influence the difference between their study and the present one.

both co-vary with the same factor.[7]

Finally, I would like to comment briefly on the *motivation*, or function of denasalization. Put differently, is there any benefit for Korean speaker/listener of bothering to produce ‘denasalized’ nasals? As has been discussed so far, denasalization or nasality weakening seems to be one instance of the phonetic phenomena called domain-initial strengthening, investigated in Cho and Keating (2001). Since this strengthening may be beneficial as an enhancement of the saliency of consonants in the domain initial position, the possibility of active control was considered by Cho and Jun (2000). "Enhancement" has two senses in this case. It is either enhancing the contrast with neighboring sounds in speech chain (syntagmatic contrast), or enhancing the contrast against the sound that can be replaced with it (paradigmatic contrast) (or both). Concerning nasal consonants, Cho and colleagues posit the hypothesis that the function of nasal weakening is to lessen the sonority and thus strengthen the "consonantality" of the nasal, i.e., enhancement of syntangatic contrast (Cho and Keating 2000: 2). Whereas Fougeron (2001) argues that, based on her experimental data on French, there seems to be no benefit for domain initial strengthening since this seems to be only a "side-effect" of prosody (Fougeron 2001: 131).

The result of the present experiment reveals a significant difference between /n/ and /m/ with only a small effect size (section 4.1), which seems to be consistent with the syntagmatic enhancement hypothesis. However, there may be other acoustic characteristics of nasals that are important for paradigmatic contrast, which is enhanced with the nasal weakening we confirmed in the present experiment. The result of Kyunggi-Do speaker is suggestive in this regard. The current result suggests, as depicted in (6b), nasality weakening is subject to a certain control in speech production, independent of durational adjustment determined by prosodic structure. This may suggest the existence of distinct sub-phonemic representations for nasality in a certain level of language production (e.g., lexicalization). If this reasoning is correct, it is not without reason to inquire if there is some paradigmatic contrast which nasal weakening enhances. One suggestion of this vein is that denasalization has a function of reducing the acoustic distortion by nasal coupling (Ohala and Ohala 1993: 230). Or alternatively, the presence of a sharp onset might enhance the salience of the different formant transitions for the labial and the coronal, thus giving a paradigmatic boost. This issue is worth investigating further.

6. Summary and future directions

The present paper reports a phonetic experiment where the sound from nostril is measured

[7] Fougeron (2001) shows the result for French nasal /n/ where significant difference is obtained between prosodic domains, i.e., IP vs. AP, Wd, Syl. This suggests there can be language/dialect specific difference for prosodic effect on nasality variation.

separately from the oral sound with manipulation of prosodic conditions. The main findings are as follows.

(1) So-called Denasalization seem to be actually *nasality weakening*.

(2) Nasality weakening is correlated with strength of prosodic boundary and varies between speakers.

(3) Nasality weakening is dialect dependent in its strength; it is stronger for Kyunggi-Do speakers than for Kyungsang-Do speakers. This may explain the cause of mis-categorization of the Korean nasal consonants as oral by non-native speakers (denasalization) which is reported to be more frequent for northern dialects.

(4) Nasality weakening does not occur prosodic-word-internally; it occurs at the initial edge of the prosodic domain equal to or larger than Prosodic Word (especially for Kyunggi-Do speakers).

(5) Nasality weakening is also dialect dependent in its dependency on the segment duration adjustment related to prosody; partial effects of duration for Kyungsang-Do speakers and no effect for Kyunggi-Do speakers.

(6) The result in (5) suggests independent control for the implementation of this weakening.

More data should be collected from a sufficient number of speakers from the dialects with different strength of denasalization and compare them to verify the observations reported here. Particularly, we need to examine further whether the dialectal difference observed here is the difference of denasalization itself, or an effect of dialectal difference in some other aspects of speech production. One possibility is that Kyungsang-Do speakers have weaker tendency to have prosodic boundaries on the same test sentence where Kyunggi-Do speakers do. This would cause the result with the weaker nasal weakening for Kyungsang-Do speakers for different reason as discussed in the preceding sections[8]. According to Jun (1998:193), prosodic phrasing is largely the same across Korean dialects. However, prosodic structure of Kyungsang-Do dialect has not been examined as closely as that of Seoul Korean. Thus, this possibility seems worth examining closely. With regard to this, more careful treatment of sentence prosody is desired. The prosodic conditions investigated here were actually morphological or grammatical conditions. Prosodic structures as expected from grammatical structures do not necessarily correspond to prosodic structure observed in phonological and intonational phenomena (Jun 1996, Utsugi 2003b). It may be more appropriate to evaluate the prosodic structure for each utterance individually and examine the correlation with nasal weakening. Finally, we should consider how we can really assess the degree of 'denasalization' itself. The acoustic measure of nasality itself, *Nmin* or *Nnorm* may not directly adressed to denasalization, because denasalization is also a matter of human response to the sound. In other words, denasalization should also be investigated in terms of speech perception.

[8] This possibility was also suggested by Akira Utsugi (personal communication).

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