Acoustic duration of Korean nasals

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Ahn, Mee-Jin. 2013. Acoustic duration of Korean nasals. *Studies in phonetics, phonology and morphology* 19.3. 411-431. This paper examines the acoustic duration of Korean nasals in three different positions and three different vowel contexts to find the relationship between the nasal weakening and the nasal duration. Korean nasals have been observed as weakened, orally released or denasalized in the word-initial position (Umeda 1957, Chen and Clumeck 1975, Ohala 1997, Takeyasu 2004, Yoshida 2008, Kim 2011). The experiment in this study reveals that the word-initial nasals are shorter than word-medial and -final nasals; the word-initial nasals are longer before vowel /i/ or /u/ than before vowel /a/; bilabial nasals are longer than alveolar nasals; the word-initial nasals lack clear visible nasal formants and 24% of word-initial nasals are partially voiceless; and alveolar nasals are more frequently devoiced than bilabial nasal in word-initial position. The findings of the experiment support that Korean nasals are weakened with their short acoustic duration in the word-initial position, in which other consonants strengthened with their longer acoustic duration. In addition, the alveolar nasals which are reported as with more frequent nasal weakening or denasalization, turned out to have shorter duration and more frequently devoiced than the other nasals. However, the effect of vowel height on the nasal closure duration suggests that the duration of nasal closure itself cannot be an invariable perceptual cue to nasality and that the quality of the nasal closure is crucial for the perception of nasality. **(Pai Chai University)**

Keywords: Korean nasals, denasalization, nasal weakening, acoustic duration, nasal closure, nasal devoicing, word-initial nasals

1. Introduction

It has been observed that Korean nasals are weakened, denasalized or orally released in the word-initial position (Umeda 1957, Chen and Clumeck 1975, Ohala 1997, Takeyasu 2004, Yoshida 2008, Kim 2011). Word-initial Korean nasals are reported to be perceived as a voiced plosive to non-native Korean speakers (Chen and Clumeck 1975, Takeyasu 2004, Kim 2011). Most phonetic studies on the Korean Denasalization are concerned with the volume of nasal airflow as an indicator of nasal weakening. (Cho and Keating 2001, Yoshida 2008, Kim 2011). In this study, I examine the acoustic duration of Korean nasals in three different positions and three different vowel contexts to find the relationship between the nasal weakening and the nasal duration. In order to compare the durational pattern of nasals with that of other types of consonant, I also measure the acoustic duration of Korean voiceless alveolar fricative /s/ in the same contexts.

2. Previous studies

It has been noticed by non-Korean speakers that Korean word-initial nasals are not fully nasalized and perceived often as a plosive. In Martin (1951), Korean nasals are described as being orally released at their end, based on his auditory and perceptual judgment. Umeda (1957) describes Korean nasal /m/ and /n/ as [mb] and [nd] where nasal murmur ceases towards the end of the segment. Chen and Clumeck (1975)'s perception test reports that Korean word-initial nasals are perceived as non-nasal, especially before a high vowel and that /m/ is more frequently perceived as non-nasal than /n/. Takeyasu (2004) distinguishes Korean nasals to three types: ordinary nasal, nonnasal voiced plosive and nonnasal voiceless plosive and defines a consonant without nasal murmur as non-nasal.

Cho and Keating (2001) explore the initial strengthening effect in Korean, according to which a consonant in higher prosodic domain-initial positions is phonetically strengthened with its longer articulatory seal duration, longer acoustic closure duration, shorter voicing duration during acoustic closure, longer VOT duration and more linguopalatal contact areas, compared to a consonant in other positions. According to their research, Korean alveolar nasal /n/ in higher domain-initial positions shows longer seal duration, more linguopalatal contact area and longer acoustic closure duration but the nasal energy minimum for nasal /n/ tends to be lower in higher domain-initial positions. Thus, Cho and Keating (2001) conclude that Korean reinforces the beginnings of prosodic domains with both lengthening and strengthening: nasals are longer in duration and weaker in energy in higher domain-initial positions.

Yoshida (2008) examines the prosodic effect of Korean denasalization. According to Yoshida (2008), Korean denasalization is incomplete and nasal weakening is not observed word-internally but only word-initially. Based on the volume of nasal airflow at the end of nasal consonant, Yoshida reports nasality weakens as the prosodic boundary becomes stronger but it doesn't show the same skeletal difference as reported in Cho and Keating (2001): nasality weakening has a two-step difference: U, IP >> AP, Wd >> Syll for Kyongsang speakers and a one-step difference: U, IP, AP, Wd >> Syll for Seoul speakers. In other words, nasality weakening is observed word-initially but not observed hierarchically at each categorical boundary such as U-, IP-, AP- or Wd-initial boundary, especially for Seoul speakers. Yoshida (2008) also reports dialectal variations in nasal weakening: nasal weakening effect is stronger for Seoul speakers than for Kyongsang speakers and stronger for /n/ than /m/.

Based on the volume of nasal airflow, Yoshida (2008) also distinguishes three types of nasality shown in Korean nasals: flat nasality for sonorant nasals, falling nasality for AP-initial or Wd-initial nasals and rising nasality for U-initial or IP-initial nasals. According to Yoshida (2008), nasals in utterance-initial position become stronger toward the end of the nasal

position due to insufficient time for the nasal energy to reach to its local target; Nasals in the AP-initial or Wd-initial position become weaker toward the end of the nasal consonant. In addition, Yoshida (2008) claims that there is no linear correlation between nasal weakening and segmental duration, based on the nasal duration rate to the following vowel duration. However, as noted in Yoshida (2008), his data for the experiment are not well-constrained: the test sentences are not identical across consonant and prosodic context conditions and such differences could affect the duration and the volume of nasal energy of the target segments, which may have contaminated his results.

Kim (2011)'s experimental works on Korean nasals reveal that Korean nasals in the word-initial position show absence of nasal formants and sometimes a visible burst mark at the end, which are similarly observed in plosives. However, Korean nasal weakening is not governed by hierarchical prosodic domains: the lowest degree of nasal air flow appears at the AP-initial position, not at the U-initial nor IP-initial position. Kim (2011)'s perception test reveals the different response to the Korean weak nasals between Korean listeners and English listeners: Korean weak nasals are perceived as nasals by Korean listeners but as voiced plosives by English listeners and denasalized alveolar nasals are more likely to be categorized as plosives than denasalized bilabial nasals for both Korean and English speakers. Limited to Korean subjects, a non-nasal segment before a high vowel are more often judged as nasals than a non-nasal segment before other vowels.

All major phonetic studies agree on that Korean word-initial nasals are not fully nasalized and often perceived as plosives to non-native Korean speakers. However, their results differ in the hierarchical prosodic-domain effect on nasal weakening: Cho and Keating (2001) report stronger nasal weakening effect at each prosodic domain-initial position while Yoshida (2008) and Kim (2011) show AP-initial or Word-initial positions as a solid boundary for nasal weakening. The height effect of the following vowel on nasal weakening is observed differently depending on the perception study; the positive effect of high vowels in Chen and Clumeck (1975), the positive effect only to Korean listeners but not to English listeners in Kim (2011) and no effect in Yoshida (2008). The place of articulation effect on the Korean nasal weakening is reported in both production and perception tests (Yoshida 2008, Kim 2011) in which nasal weakening is stronger in alveolar nasals than in bilabial nasals.[1] As for the relation between nasal duration and nasal weakening, Cho and Keating (2001) show that nasals become longer in duration and weaker in energy in higher domain-initial positions while Yoshida (2008) claims that there is no linear correlation between nasal weakening and nasal duration.

In sum, from the previous phonetic studies on Korean nasals, we can see

[1] Chen and Clumeck (1975) report the opposite in their perception study.

that there is obvious AP-initial and Word-initial prosodic effect on Korean nasals weakening: AP-initial and Word-initial nasals are weakened with low nasal energy or low volume of nasal airflow; alveolar nasals are more weakened than bilabial nasals in the word-initial position: denasalized alveolar nasals are more often perceived as plosives to Korean and English listeners; there is no consistent results on the relation between nasal weakening and nasal duration.

In this paper, I examine Korean nasal duration in different prosodic positions, word-initial, word-medial and word-final positions and different vowel contexts. The acoustic duration of Korean nasals may provide the relation between Korean nasal weakening and nasal duration. And in order to compare nasals with other consonants in the acoustic duration, the experiment includes alveolar fricative /s/ data.[2] The comparison of the acoustic duration of two types of consonants in various contexts may reveal a unique pattern of Korean nasals in the acoustic duration.

3. Experiment I

3.1 Experimental method

In the first experiment I measure the acoustic duration of Korean nasals /m/, /n/ and /ŋ/ and fricative /s/ under the identical phonetic conditions. In order only to see the segmental effect on duration, all target words in comparison have the same phonetic environment for duration except the target consonant. For example, words /komi/, /koni/, /koŋi/ and /kosi/ are used to compare the acoustic duration of m/, /n/, /ŋ/ and /s/ consonants. The words in comparison have the same word length and the same segmental composition and the target consonants are positioned in the same place within a word. Thus, the acoustic duration values drawn from the experiment are expected to reveal solely the inherent durational difference of Korean target consonants.

Table 1 shows ninety six target words which are categorized by position, syllable structure and target consonants.

[2] For the comparison of the durational pattern of nasals to that of other consonants, I selected the fricative /s/ simply because it is one of the easiest consonant for the segmentation on the spectrogram and waveforms. However, two reviewers commented that the lax stop consonants /p, t, k/ would be better and proper for the target consonant for the comparison, especially in that the word-initial nasals are frequently mis-perceived as a lax stop. I agree with the reviewers' comments, but the selection of /s/ does not invalidate the results of the present study. The comparison has been done to reveal the different behavior of Korean word-initial nasals from other consonants which have been already reported to undergo the word-initial lengthening.

Table 1. Word list of Experiment I[3, 4]

		/m/	/n/	/ŋ/	/s/
word-Initial	CVC	mam mun mil mal	nam num nil nal	*	sam sun sil sal
	CVCV	mali mukye mit^{h}ə mupi	nali nukye nit^{h}ə nupi	*	sali sukye sit^{h}ə supi
	CVCVC	makam mucən micaŋ mutaŋ	nakam nucən nicaŋ nutaŋ	*	sakam sucən sicaŋ sutaŋ
Word-Medial	CVCV	komi tomi kamu somi	koni toni kanu soni	koŋi toŋi kaŋu soŋi	kosi tosi kasu sosi
	CVCVC	səmin səmun koman, toman	sənin sənun konan tonan	səŋin səŋun koŋan toŋan	səsin səsun kosan, tosan
Word Final	CVC	pam kom sam cim	pan kon san cin	paŋ koŋ saŋ ciŋ	
	CVCVC	hesam susam kamum misim	Hesan susan kamun misin	hesaŋ susaŋ kamuŋ misiŋ	

In order to compare consonant duration by position, 36 words for the word-initial, 32 words for the word-medial and 24 words for the word-final position are selected. As shown in Table 1, neither word-initial /ŋ/ nor word-final /s/ occurs in Korean. The ninety two target words are presented in a frame sentence (1) to minimize prosodic differences.

(1) Kyesokheseo _____ palɨmhamnida.[5]
(I pronounce _____ in succession.)

[3] mam ‘heart’, nam ‘others’, sam ‘life’, mun ‘door’, nun ‘eye’, sun ‘sprout’, mil ‘wheat’, nil ‘Ø’, sil ‘thread’, mal ‘horse’, nal ‘day’, sal ‘flesh’, mali ‘unit’, nali ‘lily’, sali ‘noodle’, mukye ‘weight’, nukye ‘sum’, sukye ‘water system’, mit^{h}ə ‘meter’, nit^{h}ə ‘knitter’, sit^{h}ə ‘Ø’, mupi ‘movie’, nupi ‘quilting’, supi ‘defense’, makam ‘end’, nakam ‘going out’, sakam ‘housemaster’, mucən ‘wireless’, nucən ‘short circuit’, sucən ‘faucet’, micaŋ ‘plastering’, nicaŋ ‘Ø’, sicaŋ ‘market’, mutaŋ ‘shaman’, nutaŋ ‘eye area’, sutaŋ ‘benefit’, komi ‘bitterness’, koni ‘swan’, koŋi ‘pestle’, kosi ‘exam’, tomi ‘Ø’, toni ‘Ø’, toŋi ‘Ø’, tosi ‘arm warmers’, kamu ‘songs and dances’, kanu ‘Ø’, kaŋu ‘rainfall’, kasu ‘singer’, somi ‘Ø’, soni ‘Sony’, soŋi ‘unit’, sosi ‘Ø’, səmin ‘people’, sənin ‘good man’, səŋin ‘adult’, səsin ‘letter’, səmun ‘preface’, sənun ‘Ø’, səŋun ‘nebula’, səsun ‘Ø’, koman ‘so little’, konan ‘hardship’, koŋan ‘public peace’, kosan ‘high mountain’, toman ‘Ø’, tonan ‘theft’, toŋan ‘baby face’, tosan ‘bankruptcy’, pam ‘night’, pan ‘half’, paŋ ‘room’, kom ‘bear’, kon ‘earth’, koŋ ‘ball’, sam ‘life’, san ‘mountain’, saŋ ‘prize’, cim ‘baggage’, cin ‘camp’, ciŋ ‘cleat’, hesam ‘sea cucumber’, hesan ‘disperse’, hesaŋ ‘sea’, susam ‘fresh ginseng’, susan ‘fishery resources’, susaŋ ‘prime minister’, kamum ‘drought’, kamun ‘family’, kamuŋ ‘Ø’, misim ‘dout’, misin superstition’, misiŋ ‘sewing machine’ Here, the words with ‘Ø’ are nonsense words.

[4] In the word-initial position, the alveolar nasal /n/ before /i/ occurs only in loanwords in Korean. In Korean the alveolar nasal /n/ becomes palatalized before vowel /i/.

[5] As commented by one reviewer, the frame sentence (1) could be more natural when it contains the particle ‘-(i)la’ after the target words. However, I do not use the particle in a frame sentence in order to measure the duration of the word-final nasal. The target words in the experiment function as a Prosodic word and a Accentual phrase in the framework of the Intonational Phonology.

Five male native speakers of Korean participated in the production experiment. All four speakers are from Seoul and Kyonggi Province and are in their twenties. The speakers read 92 test sentences three times and the sentences were randomized in different orders for each repetition. The speakers were instructed to read the sentences at a comfortable pace and at a constant rate. Speech was recorded and analyzed using the Praat software for digital speech analysis. The utterance was digitized at a 16 KHz sampling rate. The duration of target consonants were measured manually from spectrograms, waveforms and amplitude curve. On the spectrogram and waveform, nasals are marked by an abrupt change at the articulatory nasal closure and appear with less energy compared to adjacent vowels. Nasals have visible formant structures similarly to vowels and they have a very low first formant about 250 Hz, a fainter second formant below 2000 Hz and the third formant about 2500 Hz (Ladefoged 2006).[6] According to Seong (1996), Korean nasals also have the first nasal formant in between 200 Hz and 300 Hz and another strong nasal formant around 2600 Hz regardless of the place of articulation of nasals, although he also reports F2 and F3 below 2600 Hz which vary depending on the place of the articulation of nasals. Fricative /s/ is easily marked by its random noise with strong energy. The spectrogram and waveform of word /səŋin/ 'adult' in Figure 1 show the segmentation of /s/ and /ŋ/.

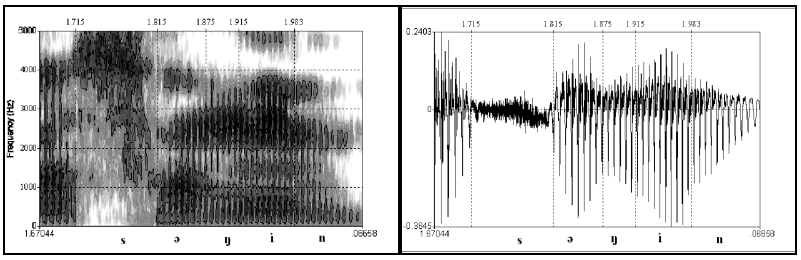

Figure 1. Spectrogram and waveform of /səŋin/ 'adult'

Figure 1 shows that fricative /s/ starts with a strong random noise without voicing and ends with the periodic waveform of the following vowel. The intervocalic /ŋ/ and the word-final /n/ appear with its nasal formants around 300 Hz and 2600 Hz with abrupt change in intensity. Due to the coarticulation with adjacent vowels, nasal energy extends over to the end of the preceding vowel and to the beginning of the following vowel. Thus, the nasal duration is marked by the first nasal formant which moves upward adjacent to the following and preceding vowel. The onset and

[6] Edwards (2003) reports that the second nasal formant is centered around 1000 Hz for bilabial and velar nasals and around 1500 Hz for alveolar nasals in English. However, the second nasal formant may be located differently depending on the place of articulation of nasals and often weakened due to the anti-resonance effect of nasals. (Stevens 1997).

offset of the low nasal formant is also accompanied with the abrupt change of intensity.

3.2 Result: Experiment I

Out of 5 subjects, Subject A who read the sentences at a relatively slow rate shows a pause after the target words and the extreme lengthening of the final target consonant in his data. Thus, the data from Subject A was removed from the analysis. The results are based on the data from the other four subjects. They read the speech material at a constant and comfortable rate and there was no pause before and after the target words.

3.2.1 Word-final consonant duration

First, consonants in the word-final position were compared in duration. Due to the absence of word-final /s/ in Korean, only the duration of nasal consonants was measured. Table 2 shows the duration classified by word-structure and the place of articulation of nasals.

Table 2. Nasal duration in word-final position (msec.)

	/m/	/n/	/ŋ/	Nasals
CV<u>C</u>	115	124	124	121 ms.
CVCV<u>C</u>	90	100	97	96 ms.

Word-final bilabial, alveolar and velar nasals are 115 msec., 124 msec. and 124 msec. long in CVC words and 90 msec., 100 msec. and 97 msec. long in CVCVC words. Two-way ANOVA analysis shows that the durations of three nasal consonants in word-final position are not statistically different in both CVC and CVCVC structure [$F(2, 282) = 4.92$, n.s.]. However, the word-size significantly affects the duration of three nasals: all three final nasals in CVC are longer than those in CVCVC structure [$F(1, 282) = 83.4$, $p < 0.001$]. The ANOVA test shows no interaction of the two factors, consonants and word structure. In Korean three different nasal consonants are not different in duration word-finally, but their duration is affected by the length of word. ANOVA analysis factored out by data or subjects shows the same result.

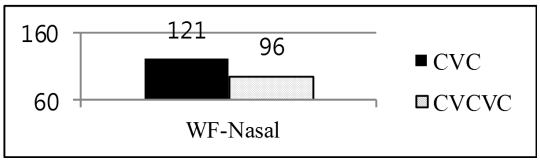

Figure 2. Word-final nasal duration by word-structure (msec.)

3.2.2 Word-medial consonant duration

All four target consonants /m/, /n/, /ŋ/ and/s/ are observed word-medially in Korean.

Table 3. Duration of four consonants in word-medial position (msec.)

	/m/	/n/	/ŋ/	/s/	Average
CV$\underline{C}$V	62	49	59	89	65
CV$\underline{C}$VC	61	45	50	67	56

Table 3 shows the average duration of four consonants in word-medial position of CVCV and CVCVC word: /m/, /n/, /ŋ/ and /s/ are 62 msec., 49 msec., 59 msec. and 89 msec. long in CVCV and 61 msec., 45 msec., 50 msec. and 67 msec. long in CVCVC. ANOVA tests confirm that the durational difference of the four consonants is significant at $F(3, 376) = 101.9$, $p < 0.001$. The post-hoc comparisons indicate that /s/ is longer than nasals; bilabial nasals are longer than velars; and velars are longer than alveolar nasals. In addition, consonant durations are statistically different depending on the word-structure: the medial consonant duration is longer in CVCV than in CVCVC [$F(1, 376) = 50.1$, $p < 0.001$].

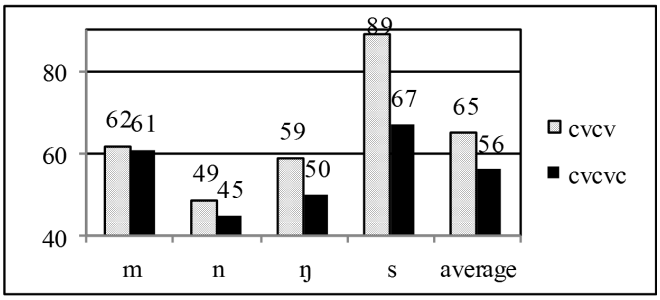

Figure 3. Duration of four consonants in word-medial position

ANOVA tests on the medial consonant duration factored out by subjects and data produce the same result.

3.2.3 Word-initial consonant duration

Due to the absence of the velar nasal in the word-initial position, data of /m/, /n/ and /s/ are collected for the word-initial consonant duration. However, word-initial nasals do not show the same nasal formants which appear word-medially and word-finally. Nasals are expected to have visible formant structures around 300 Hz and the third formant around 2600 Hz in

spectrogram, as in the nasal /n/ of word /toni/ 'Ø' in Figure 4.[7]

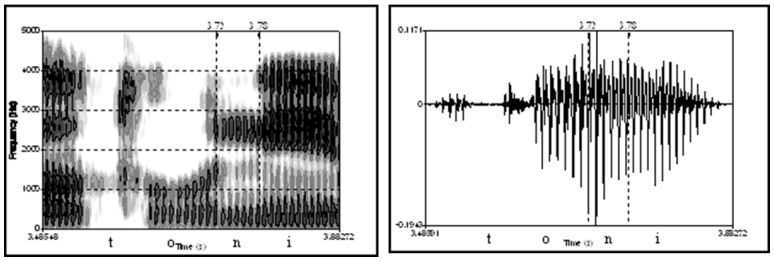

Figure 4. Spectrogram and waveform of word-medial nasal /n/ in word /toni/ ('Ø')

However, none of 288 word-initial nasal tokens show the same clear nasal formants around 2600 Hz during their closure, regardless of the place of articulation or word structures. A few bilabial tokens show the second and third nasal formants which get faint during the closure duration, as shown in Figure 5. The nasal murmur gets weaker during the oral closure of the bilabial nasal /m/ in /mal/ ('speech').

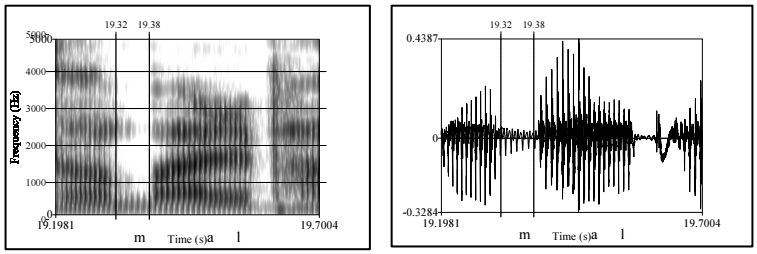

Figure 5. Spectrogram and waveform of bilabial nasal /m/ of /mal/ ('speech')

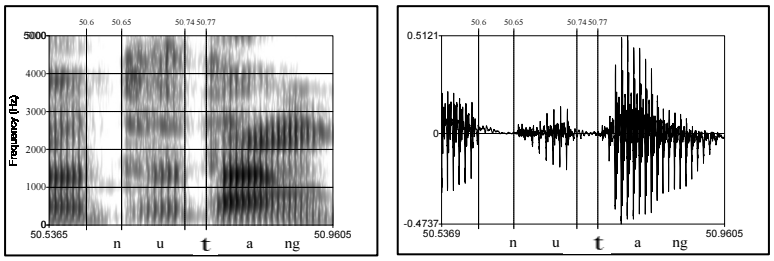

Figure 6. Spectrogram and waveform of word /nutaŋ/ ('eye area')

The other word-initial nasals have only low-frequency energy below 300 Hz, which gets reduced toward the end of the nasal closure, as shown in Figure 6. The alveolar nasal /n/ of /nutaŋ/ ('eye area') in Figure 6 begins

[7] In Korean, the alveolar nasal is palatalized in between vowels (Lee 1996).

with the low-frequency energy but ends without the visible periodic waves.[8] The spectrogram and waveform in Figure 6 show that the alveolar /n/ is similar to the alveolar /t/, which is realized as voiced [d] in Korean. Both sounds show the low-frequency energy and periodic waves at the beginning of the closure, which get weakened toward the end of the oral closure. It is hard to discern between the nasal murmur and the low-frequency energy resulting from voicing based on the spectrogram or the waveform, especially when the low-frequency energy is weak. In addition, there is no audible acoustic sound during the nasal closure.

Among word-initial nasals, some nasals do not even show periodic waves during their closure duration, as shown in the spectrogram and the waveform of /n/ of word /napi/ 'butterfly' in Figure 7. The alveolar nasal /n/ does not present voicing bars or periodic waves. Some other word-initial nasals are observed even to fricate the following vowel and to make it voiceless at the beginning.

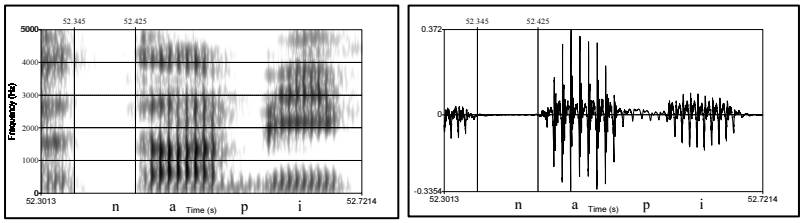

Figure 7. Spectrogram and waveforms of word-initial nasal /n/ in word /napi/ ('butterfly')

All these observations suggest that Korean word-initial nasals are significantly different from word-medial and word-final nasals. And it is difficult and not reliable to measure the duration of word-initial nasals based on the visible nasal formant in Korean. Thus, the duration of word-initial /s/ was measured and analyzed from Experiment I.

Table 4. Duration of word-initial /s/

	CVC	CVCV	CVCVC	Average
/s/	101	101	99	100

As shown in Table 4, the average durations of word-initial /s/ are 101 msec. in CVC and CVCV and 99 msec. in CVCVC words. However, their durational difference was not significant statistically [$F(2, 132) = 0.82$, n.s.] In other words, word-initial [s] duration is not influenced by the word-structure.

[8] In Korean, voiceless stops are voiced in between vowels.

3.2.4 /s/ duration by position

Korean /s/ occurs in the word-initial and word-medial positions, but not in the word-final position. The durational comparison of /s/ by position indicates that /s/ is longer word-initially than word-medially in both CVCV and CVCVC structures, as in Table 5. The durational difference by position is statistically significant at $F(1,188) = 57.7$, $p < 0.001$.

Table 5. Duration of /s/ in word-initial and word–medial positions (msec.)

	CVCV	CVCVC	Average
Word-Initial	101	99	100
Word-Medial	89	67	78

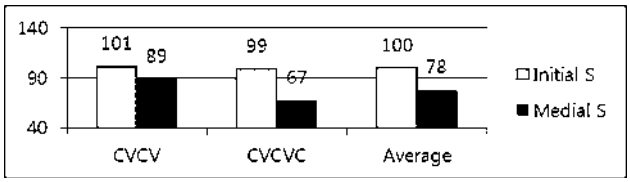

Figure 8. Duration of /s/ in word-initial and word–medial positions (msec.)

3.2.5 Nasal duration by position

Due to the lack of a fully visible nasal formant structure in word-initial nasals, the acoustic durations of three nasals /m/, /n/, /ŋ/ were compared only in word-medial and word-final positions.

Table 6. Word-medial and final Nasal durations in CVCVC

	/m/	/n/	/ŋ/	Average
Word-Medial	61	45	50	52
Word-Final	90	100	97	96

Table 6 shows that word-medially nasals are 52 msec. long while they are 96 msec. long word-finally. Two-way ANOVA test confirms that duration of three nasals is significantly different depending on the position at $F(1, 282) = 507.5$, $p < 0.001$.

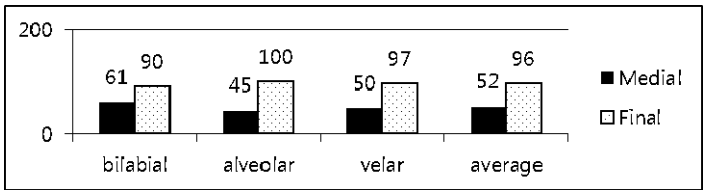

Figure 9. Word-medial and final nasal durations in CVCVC

4. Experiment II

4.1 Acoustic duration of word-initial nasals and /s/ in three different vowels

Experiment II is designed to examine the word-initial duration of nasal /m/ and /n/ and fricative /s/ before three different vowels, /i/, /a/ and /u/. As shown in experiment I, nasals do not show their typical nasal formants or voicing cues in word-initial position. Thus, Experiment II measures the acoustic closure duration of nasals even if the acoustic closure does not contain solid nasal formant structures. The acoustic duration of nasal closure is marked from the end of first formant lowering of the preceding vowel to the beginning of the first formant rising of the following vowel, as in Experiment I. Figure 10 shows that the nasal closure duration of /n/ in /nupi/ (‘quilting’) is marked by the offset and onset of the preceding and following vowels. If there is a visible nasal release burst mark at the end of nasals, which is not observed word-medially and word-finally, the acoustic closure duration of nasals is measured from the end of the preceding vowel to the nasal release e mark, as illustrated in Figure 11. The closure duration of the word-initial nasal /n/ in /nali/ (‘lily’) is marked from the offset of the preceding vowel to the point of the nasal release burst on the spectrogram, as shown in Figure 11.

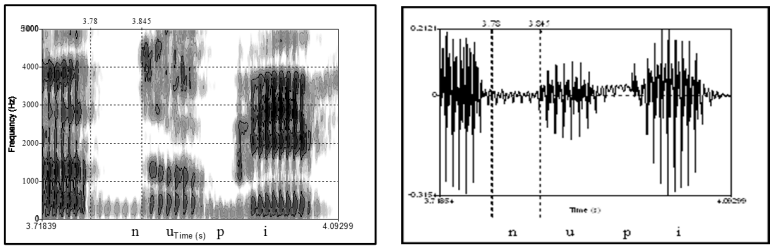

Figure 10. Duration of /n/ in /nupi/ (‘quilting’)

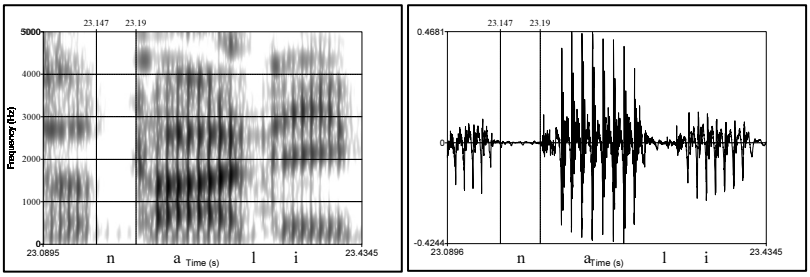

Figure 11. Duration of /n/ in /nali/ (‘lily’)

Experiment II adopts the same experimental method of Experiment I: the

same four male Korean speakers from Seoul and Kyonggi province participated in the recording and Praat program was used for the recording and analysis. Thirty six test words were selected for Experiment II: twelve /m/-initial words, twelve /n/-initial words and twelve /s/-initial words. Each of 12-word group is classified by the quality of the following vowel and the word structure, as shown in Table 7: three word-initial consonants are followed by one of three vowels, /i/ /a/ and /u/ and positioned either in CVCV or CVCVC words. The test words are presented in the same frame sentence as in Experiment 1. Subjects read the 36 test sentences which are randomly ordered three times.

Table 7. Word list of Experiment II[9]

		/a/	/i/	/u/
/m/	CVCV	mat^{h}ɨ, mali	mit^{h}ɨ, mili	mut^{h}ɨ, muli
	CVCVC	macaŋ, masul	micaŋ, misul	mucaŋ, musul
/n/	CVCV	nali, napi	nili, nipi	nuli, nupi
	CVCVC	nacin, nacən	nicin, nicən	nucin, nucən
/s/	CVCV	sakye, sapi	sikye, sipi	sukye, supi
	CVCVC	sacaŋ, sakam	sicaŋ, sikam	sucaŋ, sukam

4.2 Results

4.2.1 Word-initial /s/ duration in different vowels[10]

The duration of /s/ preceding vowel /a/ is 87 msec. in both CVCV and CVCVC, the duration of /s/ preceding /i/ is 110 in CVCV and 101 in CVCVC and the duration of /s/ preceding vowel /u/ is 107 msec. in CVCV and 112 msec. in CVCVC, as shown in Table 8.

[9] mat^{h}ɨ 'mart', mit^{h}ɨ 'meat', mut^{h}ɨ 'moot', mali 'counting unit', mili 'in advance', muli 'group', macaŋ 'a race course', micaŋ 'plastering', mucaŋ 'to arm', masul 'magic', misul 'fine art', musul 'martial arts', nail 'lily', nili 'Ø', nuli 'world', napi 'butterfly', nipi 'Ø', nupi 'quilting', nacin 'Ø', nicin 'Ø', nucin 'gradual advance', nacən 'nacre', nicən 'Ø', nucən 'short circuit', sakye 'four season', sikye 'watch', sukye 'water system', sapi 'one's own money', sipi 'right or wrong', supi 'defence', sacaŋ 'CEO', sicaŋ 'market', sucaŋ 'group head', sakam 'housemaster', sikam 'poetic inspiration', sukam 'imprisonment'

[10] In order to see whether the experiments I and II derive the same durational pattern, I compared word-initial /s/ durations in the two experiments. Since the word-initial /s/ duration is influenced by the quality of the following vowel, I include only data which have the same following vowels for the comparison. The average duration of word-initial /s/ is 100 msec. long in Experiment I and 102 msec. long in Experiment II. ANOVA tests confirm that the two sets of data do not show different values of duration at the significance ($p < 0.001$). It validates the results of the two experiments are consistent.

Table 8. Duration of word-initial /s/ (msec.)

	Before /a/	Before /i/	Before /u/	average
CVCV	87	110	107	107
CVCVC	87	101	112	112
Average	87	105	109	

ANOVA tests reveal that the word-initial /s/ duration of CVCV is not different from that of CVCVC while word-initial /s/ duration varies depending on the quality of the following vowel at $F(2,138) = 15.6$, $p < 0.001$. The post-hoc analysis presented that the word-initial /s/ preceding /a/ is longer than the word-initial /s/ preceding /i/ or /u/, but that there is no difference in duration between /s/ preceding /i/ and /s/ preceding /u/, as in Figure 12.

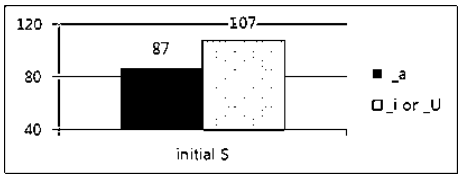

Figure 12. Duration of word-initial /s/ (msec.)

4.2.2 Acoustic closure duration of word-initial nasals

First, word-initial alveolar nasals are 48 msec. in CVCV and CVCVC structure and bilabials are 58 msec, as in Table 9. ANOVA tests present that nasal duration is not affected by the word structure of CVCV or CVCVC at ($F(1, 284)=0.05$, n.s.), while it is influenced by the place of articulation of nasals at the significance ($F(1, 284) = 48.2$, $p < 0.001$). The post-hoc comparison observed that bilabial nasals are longer than alveolar nasals. The same result was observed in word-medial position in the experiment I.

Table 9. Acoustic closure duration of word-initial nasals (msec.)

	/m/	/n/
CVCV	58	48
CVCVC	59	48
Average	59	48

Next, the analysis of word-initial nasal closure duration by the quality of the following vowel shows that nasals are longer before vowel /i/ or /u/ than before vowel /a/, as shown in Table 10.

Table 10. Word-initial nasal closure duration by the quality of the following vowel (msec.)

	__ /a/	__ /i/	__ /u/
/m/	48	60	66
/n/	40	54	48
Average	44	57	57

ANOVA test shows that the nasal closure duration is significantly different depending on the quality of the following vowel and the place of articulation of nasals [$F(2, 282) = 47.5$, $p < 0.001$), $F(1, 282) = 66.4$), $p < 0.001$]. The post-hoc comparisons show that both bilabial and alveolar nasals preceding a low vowel /a/ are shorter than those preceding high vowels /i/ or /u/ in the closure duration; alveolar nasals preceding /i/ have longer closure duration than those preceding /u/ whereas bilabial nasals do not show such a difference.

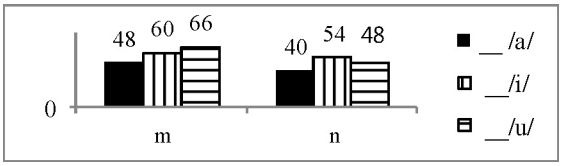

Figure 13. Word-initial nasal closure duration by the quality of the following vowel

4.2.3 Nasal duration by position

To examine the durational pattern of nasals by position, the data of Experiment I and II are compared as shown in Table 11. This comparison does not reflect the whole nasality of nasal consonants since the closure duration of word-initial nasals do not contain solid nasal murmur during their articulatory closure. However, this comparison reflects the articulatory closure duration of nasals in three different positions. For the comparison I include only data which have the same word structure and the same following vowels since the duration is affected by those factors.

Table 11. Duration of word-initial and word-medial nasals (msec.)

		Initial	Medial
/m/	cvcv	63	63
	cvcvc	57	61
/n/	cvcv	52	50
	cvcvc	46	46
Average		54.5	55

Word-initial bilabial nasals are 63 msec. long in CVCV and 57 msec. long in CVCVC and word-medial bilabial nasals are 63 msec. long in CVCV and 61 msec. long. The durational difference of bilabial nasals by position

was statistically not significant. Word-initial alveolar nasals are 52 msec. long in CVCV and 46 msec. long in CVCVC and word-medial alveolar nasals are 50 msec. long in CVCV and 46 msec. in CVCVC. The duration difference of alveolar nasals by position was not statistically significant. Therefore, it is evident that the word-initial nasal is not different from the word-medial nasal in the closure duration in Korean and that there is no initial strengthening effect on the closure duration of nasals in Korean.

Figure 14 compares the average duration of bilabial and alveolar nasals of a CVCVC word, which was selected for a target word structure in all three word-initial, word-medial and word-final positions. Statistical analyses conducted in Experiment I and II prove that word-final nasals are longer than word-medial and word-initial nasals in Korean.

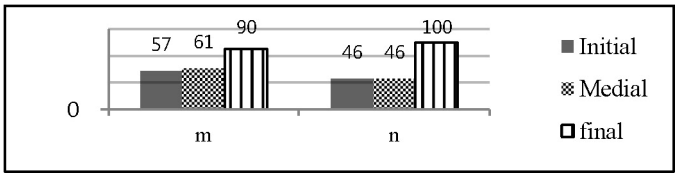

Figure 14. Word-initial, -medial and –final nasal duration in CVCVC

4.2.4 Voicing of word-initial nasals

As reported in Experiment I, Korean word-initial nasals do not show solid nasal formants. During the articulatory oral closure, some nasals do not even show their acoustic voicing cue on the spectrogram and waveform. Experiment II counted how many word-initial nasals present voicing acoustic cues during their articulation. Among 288 counts (24 nasals *3 repetition *4 speakers) of word-initial nasals of Experiment II, 69 nasals were partially or fully voiceless during their nasal closure without voicing bars and periodic waves on the spectrogram and waveform.

Table 12 shows that 13 (9%) out of 144 bilabial nasals are voiceless while 56 (38%) out of 144 alveolar nasals are voiceless: in Korean, alveolar nasals occur as voiceless more frequently than bilabial nasals do in the word-initial position.

Table 12. Voiceless nasals out of 288 word-initial nasals

	N _	Voiceless N	Total (24%)
m	__ a	4	13 (9%)
	__ i	1	
	__ u	7	
n	__ a	19	56 (38%)
	__ i	20	
	__ u	17	

5. Results and discussion

The results from Experiment I and II reveal that Korean nasal duration is influenced by its position within a word, its place of articulation and the quality of its following vowel. The duration of Korean /s/ in comparison with Korean nasals also shows the effect of its position within a word and the quality of the following vowel.

First, the duration of Korean /s/ is longer word-initially than word-medially. Due to the absence of Korean /s/ in the word-final position, it is only possible to compare the duration of /s/ in the two positions. The longer duration of the word-initial /s/ is predicted by Cho and Keating (2001)'s Domain Initial Strengthening Effect. On the other hand, Korean nasals show a different durational pattern from Korean /s/: word-final nasals are the longest in duration, but word-medial and word-initial nasals do not show difference in their closure duration. That is, Domain Initial Strengthening Effect does not apply to Korean word-initial nasals. The relative short duration of word-initial nasals may arise from the idiosyncratic pattern of Korean nasals: unlike other consonants, nasals may have short duration at word-initial position. Or the idiosyncratic short duration of word-initial nasals may arise from the discrepancy between the articulatory duration and the acoustic duration. It might be possible that the articulatory closure duration of word-initial nasals are longer than the acoustic closure duration of word-initial nasals.[11] For the relation between the acoustic and articulatory duration of word-initial nasals, a further research is required.

Second, both Korean nasals and /s/ show the effect of the quality of following vowel on their duration in the word-initial position. Both types of consonants are longer before high vowels /i/ and /u/ than before low vowel /a/. This result may arise to maintain the consistent duration of a consonant and its following vowel within the same syllable since low vowel /a/ is longer than high vowel /i/ or /u/.[12] Or, the degree of co-articulation of a consonant and a vowel may lead to the different consonant duration. In fact, the spectrogram data in Experiment I and II showed that fricative /s/ and nasals /n/ and /m/ are more co-articulated with vowel /i/ or /u/ than vowel /a/. In sum, the duration of Korean nasals and /s/ varies depending on the quality of the following vowel.

Third, Korean nasal duration is influenced by its place of articulation: bilabial nasal are longer than alveolar or velar nasals in the word-initial and word-final positions. However, in the word-final position, nasals do not

[11] However, Cho and Keating (2001) noted that the measured acoustic duration was generally longer than the measured articulatory seal duration.

[12] It is notable that English has a tendency to maintain the consistent duration of a vowel and its following consonant within the same syllable, not of a vowel and its preceding consonant. As for the effect of a consonant on the duration of the following vowel in Korean, there are studies such as Chung et al. (1999) and Choi (2011).

show any difference in duration depending on their place of articulation. The extreme long duration of nasals in word-final position might override the effect of the place of articulation on the nasal duration.

Forth, it was proved that the word-length or word-structure is another factor to influence the duration of Korean nasals and fricative /s/. In the word-final position, nasals are longer in a CVC word than in a CVCVC word. In the word-medial position, intervocalic consonants are longer in a CVCV than in a CVCVC structure. However, the effect of the word structure on the duration disappears in the word-initial position: the consonant duration of nasals and /s/ does not vary depending on the word structure in the word-initial position.

Fifth, it is notable that Korean word-initial nasals do not show a fully visible nasal formant structure which clearly appears word-medially and word-finally. Besides the lack of solid nasal formants, the loss of voicing is observed in 24% of Korean word-initial nasals without visible voice bars or periodic sound waves during the nasal closure as in Table 12. Especially alveolar nasals are more frequently devoiced than bilabial nasals in the word-initial position. Cho and Keating (2001) also observe that the phonetic initial strengthening effects in Korean accompany reduction of voicing and nasal energy. Kim (2011) also points out the lack of visible nasal formants in the word-initial position.

So far, we have seen the acoustic durations of three Korean nasals and fricative /s/ and their durational variations by the position within a word, the place of articulation, the word structure and the quality of the following vowel. Turing back to the Korean Denasalization, Korean word-initial nasals are reported as "denasalized" or "weakened" by Umeda (1957), Chen and Clumeck (1975), Ohala (1997), Takeyasu (2004), Yoshida (2008) and Kim (2011). The reported "Korean denasalization" phenomena are summarized as the following in (2).

(2) Korean Nasal Weakening, Denasalization
   a. Only word-initial nasals are perceived as non-nasals.
   b. Alveolar nasals are more frequently perceived as non-nasals.
   c. Nasals before a high vowel are more frequently perceived as non-nasals

The observations in (2a and b), in which word-initial nasals only are denasalized and alveolar nasals are more denasalized, may be accounted for by the durational pattern of Korean nasals from Experiment I and II: the acoustic cue of duration may function as a positive perceptual cue to nasality and word-initial nasals and alveolar nasals with short acoustic duration tend to be more denasalized. However, the durational pattern of Korean nasals by the following vowel quality presents the opposite pattern: the nasals with the longer acoustic duration before a high vowel tend to be more frequently denasalized.

This contradictory relationship between the acoustic duration and denasalization should be accounted for by the quality of the acoustic duration since the word-initial nasals do not accompany with their typical nasal murmur during the reported acoustic duration. The long closure duration without typical nasal murmur may rather hinder accurate perception of nasals. The frequent densalization of alveolar nasals is also accounted by the quality of the nasal murmur as well as the acoustic duration: alveolar nasals are more frequently devoiced than bilabial nasals in the word-initial position in Korean as in Table 12. Nasals without concomitant voicing will have a major effect on perception (Ohala 1975). Thus, Korean denasalization should be accounted for by both the acoustic duration as well as the quality of nasal murmur during the closure duration.

Despite of the reported Korean Nasal Weakening, it is true that native Koreans have no problem with perception of Korean word-initial nasals which have a relatively short acoustic duration lacking nasal formants or often without voicing. It suggests that there must be other acoustic cues such as the transition cues from a nasal to a vowel, the transition cues from a vowel to a nasal and the nasal release cue, which function for Korean's perception of word-initial nasals. In fact, the spectrogram data in Experiments I and II often show the strong nasal release mark of Korean word-initial nasals which is absent in word-medial and final. Thus, it might be possible that the strong nasal release of word-initial nasals compensates for the weak acoustic cues of nasality during the nasal closure in Korean. For the solid accounts for the relationship between acoustic cues and perception within a language or across languages, a further research is required.

6. Conclusion

The Experiment I and II reveal the acoustic durational pattern of Korean nasals in comparison to Korean fricative /s/: the duration of Korean nasals and /s/ is longer before vowel /i/ or /u/ than before vowel /a/; the duration of Korean nasals and /s/ varies depending on the word length in the word-medial and final position but not in the word-initial position; Korean word-initial nasals are not longer than word-medial and -final nasals, whereas Korean word-initial /s/ is longer than word-medial /s/; the duration Korean nasals varies depending on their place of articulation; bilabial nasals are longest and velar nasals are longer than alveolar nasals; Korean word-initial nasals lack a fully visible nasal formants and 24% of word-initial nasals are partially voiceless; Korean alveolar nasals are more frequently devoiced than Korean bilabial nasal in word-initial position.

As mentioned in section 2, there has been no solid research and consistent result on the relation between nasal weakening and nasal acoustic duration. This research proves that Korean nasals are weakened with their short acoustic duration in the word-initial position, in which

other consonants strengthened with their longer acoustic duration. However, the effect of vowel height on the acoustic closure duration suggests that the duration of nasal closure itself cannot be an invariable perceptual cue to nasality and that the quality of the nasal closure is crucial for the perception of nasality. In sum, Korean word-initial nasals have short acoustic duration, compared to other word-initial consonants and are weakened without typical nasal formant structure and partial devoicing during the closure.

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