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Pitch Accent Realization in North Kyungsang Korean: Tonal Alignment as a Function of Nasal Position in Syllables

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ABSTRACT

This study investigates patterns of the alignment of the accentual peaks in bisyllabic words of the CVNCV, CVNV, and CVNNV structures in North Kyungsang Korean. Based on the tonal alignment, patterns of the F0 pitch excursion are discussed relative to one another. Issues are addressed concerning how the tonal targets are aligned, and how the tonal specifications of nasals in postvocalic, intervocalic, and prevocalic environments are supplied in the LH, HL, and HH classes. Tonal specification of nasals in various environments is accounted for by extension of the L target, displacement of the pitch peak, and interpolation between two tonal targets, depending on the tonal class. The results in this study provide preliminary evidence that the categorical alignment of the tonal targets is implemented by simply checking the presence or absence of a nasal before or after the nucleus vowel on the segmental string, without reference to the constituency of the nasal in the syllable structure. However, the prosodic structure has a key role to play in explaining speaker-dependent variations in the tonal alignment. Sensitivity to tautosyllabicity has an effect on the shape of the F0 contour, and disparity in the patterns of the pitch excursion is represented as a function of syllable structure correlated with segmental composition of the nasal.

Key words: extension of the L, F0 contour, nasals, peak delay, pitch excursion, pitch peak, syllable structure, tautosyllabicity, tonal alignment, tonal displacement, tonal interpolation, tonal target

1. Introduction

In the autosegmental account, a tone is canonically associated with each vowel in the segmental string since it is the vowel that constitutes the nucleus in the syllable. However, subsequent phonetic research has revealed that tonal targets are not necessarily realized on the vowels in their alignment. This study is motivated by the general observation in tonal and intonational phonology that F0 peaks are often displaced to the right of the syllable nucleus or even to the right of the syllable associated with the high tone (Grabe, 1998 (for English); Arvaniti, Ladd and Mennen, 1998 (for Greek); Prieto, van Santen and Hirschberg, 1995 (for Mexican Spanish); Xu, 1998, 1999, 2001; Li, 2005 (for Chinese)).

The tonal system of North Kyungsang Korean (henceforth NKK) has been studied by many researchers (G. Kim, 1988; Y. Chung, 1991; Kenstowicz and Sohn, 1997; Sohn, 2001a, b, 2004; Jun, et al., 2006; N. Kim, 2010). Regardless of their theoretical frameworks, it is commonly assumed that there are three tonal classes of LH, HL, and HH in this dialect. In the case of bisyllabic words, the LH class surfaces when the accentual peak falls on the second syllable of a bisyllabic word. The pitch-accented vowel is associated with the H tone of the tonal melody HL, and the initial vowel which is left toneless is filled with the default L tone later in postlexical phonology, as shown below:

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(1) The LH class

```
                 *
(C)  V (C C) V
     |       |
     L       H  L
```

On the other hand, the HL class arises when the pitch accent appears on the initial syllable. The initial pitch-accented syllable is associated with the H tone of the tonal melody HL, and the second vowel with the L, hence resulting in a phonological representation as in (2):

(2) The HL class

```
     *
(C)  V  (C C) V
     |        |
     H        L
```

The HH class surfaces as doubled representation of the H in the tonal melody. The H is first associated with the second vowel bearing the pitch accent and then is spread backward to the initial vowel, as shown in (3)[2]:

(3) The HH class

```
               *
(C)  V (C C) V
             |
             H  L
```

Phonological representation, however, is not sufficient to account for the details of tonal phenomena since mismatch arises between segments and tones in the course of phonetic implementation. Discrepancy between the canonical phonological representation and phonetic mapping of the target tones has been well documented in tonal and intonational phonology of many languages (Silverman and Pierrehumbert, 1990; Arvaniti, Ladd and Mennen, 1998; Prieto, van Santen and Hirschberg, 1995; Grabe, 1998; Xu, 1998, 1999, 2001; Ladd et al., 1999; Atterer and Ladd, 2004; and Li, 2005 among others). Viewed in this context, phonological representation of the LH, HL and HH classes in NKK brings forth the issue of tonal specification of the intervening segments between two tonal targets. For phonologically unspecified tone-bearing units, it is generally accepted that these segments receive tonal specification through interpolation of the neighboring target tones (Arvaniti and Ladd, 1995). In this study tonal interpolation refers to the phonetic implementation, whereby a phonologically unspecified intervening segment becomes specified as a consequence of bridging the two adjacent specified tonal values[3].

As for the experimental studies of the NKK tone, Hong (2007) examined the tonal effect of prevocalic consonants on vowels in the word-level. In Utsugi and Jang (2008), various aspects of the tonal alignment and scaling in NKK were accounted for as a function of the number of syllables through the turning point detection to the F0 contours by examining the upstep and downstep. To the best of my knowledge, however, substantial attention has not been placed on the tonal specification of intervening segments between the target tones in the wake of the tonal alignment of the accentual peak in NKK. Nasals are particularly intriguing due to their asymmetric function in syllable structure, namely that [m] and [n] may hold in any position in syllable, whereas [ŋ] is restricted to coda.

Employing the asymmetric syllabic constituency of nasals, this study addresses the issues concerning how the tonal targets are aligned and scaled on nasals in postvocalic, intervocalic, and prevocalic environments, and how the tonal specification of intervening nasals is supplied, depending on three tonal classes of the LH, HL and HH. This study also attempts to account for the way in which the H target is displaced to the right of the nucleus vowel or even to the right of the syllable, hence showing the pitch peak delay, and the way in which the L target is extended beyond the nucleus vowel, as a counterpart to the pitch peak delay of the H target. Based on the tonal alignment, variable patterns of the F0 pitch excursion are discussed relative to one another as a function of structural asymmetry of nasals. In order to carry out the present investigation, an experiment was designed to derive the F0 pitch excursion of bisyllabic words in three types of the CVNCV, CVNV and CVNNV syllable structures, each structure comprising three tonal classes of the LH, HL and HH. Based on the excursion of the F0 pitch movement on the nucleus vowels and their intervening nasals, the present discussion lays emphasis on their tonal alignment and scaling along two dimensions of the horizontal and vertical axis.

2) Phonological representation for this class of nouns varies depending on the theoretical framework (G. Kim, 1988; Y. Chung, 1991; Kenstowicz and Sohn, 1997; N. Kim, 2010), but researchers agree on the doubled representation of the H in the surface.

3) This is similar to the segmental effect of nasal specification supplied by interpolation between two specified nasal targets in the phonetic implementation, as discussed in Cohn (1990).

2. The Experiment

2.1. Materials

An experiment was designed to explore the patterns of the F0 peak alignment. To establish whether or not there are differences in the F0 pitch excursion of the vowels and their adjacent nasals depending on the syllable structure and the type of the tonal class, the experiment employed bisyllabic words containing nasals.

The materials in this experiment consist of three sets of bisyllabic words in three types of CVNCV, CVNV and CVNNV syllables. Each set of data comprises three tonal classes of the LH, HL, and HH; each tonal class comprises three nasal stops [m, n, ŋ] in the position specified by N in each syllable structure. Thus, the first two sets of data relating to CVNCV and CVNV syllable structures consist of 18 test words, each syllable type consisting of 9 words (including three nasals by three tonal classes). A third set of data for CVNNV syllable structure includes a sequence of two nasals. Due to place assimilation (Sohn 2008) and phonotactic constraint prohibiting velar nasal on onset position in Korean, however, possible combinations of nasals are limited to five sequences of [nn], [mm], [mn], [ŋm], and [ŋn]. Each sequence is realized in three different tonal classes, hence yielding 15 tokens. Taken all together, three sets of data make up 33 test words.

2.2. Subjects and Procedures

Three native speakers of North Kyungsang Korean participated in the experiment: YK, LJ and SW. They are male students in their twenties, all affiliated with a university in Daegu. None of the speakers had any known speech problem and were aware of the purpose of the experiment.

The recording was conducted on a digital audio tape (DAT) in a sound-treated room. The speech signal was digitized at 16 KHz. Test words were put into a carrier sentence "ikes-un ___ ita", meaning 'This is (a) ___.' The subjects were instructed to read the sentences as naturally as possible after taking some time to be familiar with the material. They read each test word twice from a randomized list typed in Korean. The recording was monitored and the speakers were asked to repeat any misread or unnatural word. The target words were segmented by the author from waveform and spectrogram displays using Praat version 5.1.07. Measurements of the F0 pitch excursion on major segments and duration of nasals were manually extracted from the target words. In order to derive the relative degree of the pitch peak delay when the peak does not appear on the nucleus vowel, the temporal distance is measured from the onset of nasal to the pitch peak.

3. Results

First of all, the F0 pitch values for the first and second vowels and their intervening nasals are measured in each syllable type. In case where there is fluctuation of the F0 pitch in the duration of a segment, the highest F0 value is taken regardless of whether the target tone for the segment is the L or H. In the case of the CVNCV and CVNV structures, the pitch values of 9 tokens were averaged out across all three types of tonal classes (three test words in each tonal class by three speakers), while the pitch values of 15 tokens were averaged out in the case of the CVNNV structure (five test words in each tonal class by three speakers). The F0 pitch value on major target segments is given below:

	LH			HL			HH		
	V1	N	V2	V1	N	V2	V1	N	V2
CVNCV	110.0	114.0	139.0	124.3	141.0	126.3	119.0	134.3	141.0
CVNV	110.2	132.3	139.6	138.1	149.6	143.6	124.0	141.6	144.6
CVNNV	113.1	127.6	142.1	152.0	166.6	143.3	129.5	148.0	147.5
Avg.	111.1	124.6	140.2	138.1	152.4	137.7	124.1	141.3	144.3

Table 1. Average F0 pitch value of vowels and nasals (Hz)

In the LH class the lowest F0 pitch on the initial vowel is on the increase during the postvocalic nasal and the highest F0 pitch occurs in the second vowel. In the HL class, however, the highest F0 pitch does not occur on the initial vowel; it takes place on the postvocalic nasal, hence showing the pitch peak delay. The first H tone in the HH class is similar to the H in the HL class in that its pitch peak is delayed to the postvocalic nasal. In this tonal class the second H is slightly higher than its first H.

Second, the duration of nasals is measured in three syllable structures. The duration of nasals in table 2 is the average of 9 tokens for each type of the CVNCV and CVNV structures (three nasals in three tonal classes), while it is the average of 15 tokens for the CVNNV structure (five types of nasal sequences in three tonal classes).

	CV<u>N</u>CV	CV<u>N</u>V	CV<u>NN</u>V
YK	91.8	73.2	127.4
LJ	85.2	62.1	116.4
SW	100.2	76.2	132.7
Avg.	92.4	70.5	125.5

Table 2. Average duration of postvocalic nasals (ms)

The table above shows that the duration of nasal is longer in coda (CVNCV) than in onset position (CVNV). Naturally, a sequence of two nasals in CVNNV is much longer than any nasal in the CVNCV or CVNV structure, if not longer than the sum of two singleton nasals in the latter two structures.

Third, temporal distance was measured between the onset of the nasal and the pitch peak when the peak was displaced to the right of the vowel, as in the H target of the HL class and the first H target of the HH class. The LH class does not show the pitch peak delay, reaching the peak for the H target at the onset of the second vowel or immediately after its onset[4]. What appears in table 3 is the average pitch peak delay of the H target of the HL class and the first H target of the HH class in the CVNCV structure[5].

	HL			HH		
	Peak delay (ms)	Nasal dur. (ms)	Delay ratio	Peak delay (ms)	Nasal dur. (ms)	Delay ratio
YK	50.0	92.0	0.54	63.6	96.6	0.66
LJ	51.0	72.0	0.71	61.6	100.0	0.66
SW	42.0	94.0	0.44	82.6	106.3	0.78
Avg.	47.6	86.0	0.56	69.2	100.9	0.70

Table 3. Pitch peak delay in CVNCV structure: HL & HH classes

Derivable from two measurements, namely the total duration of the nasal and the distance between the onset of the nasal and the point of the pitch peak, is the ratio of the pitch peak delay. The peak delay ratio is computed as a function of the peak delay out of the total duration of the nasal. Total duration of the nasal, the temporal distance representing the pitch peak delay and the ratio of the peak delay are all greater in the first H target of the HH class than in the H target of the HL class. Higher peak delay ratio for the HH class suggests that the F0 pitch peak is relatively more delayed when the nasal is longer as in the HH class.

Given below is the general ratio of the pitch peak delay in the CVNCV structure regardless of the tonal class:

	Peak delay (ms)	Nasal dur. (ms)	Delay ratio
YK	57.0	91.8	0.59
LJ	56.2	85.2	0.68
SW	62.3	100.2	0.62
Avg.	58.5	92.4	0.63

Table 4. Pitch peak delay in CVNCV structure

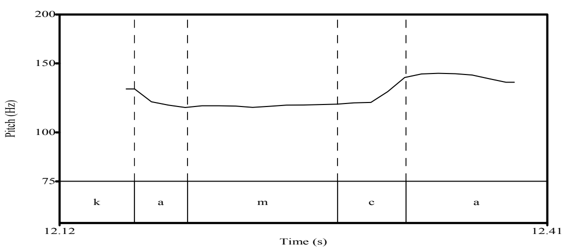
According to the peak delay ratio, the F0 pitch peak of the H target is realized approximately after midpoint in the nasal, ranging from 59% to 68%.

It is to be noted here that the temporal distance denoting the pitch peak delay was not measured for CVNV and CVNNV structures, since the pitch excursion of the H target was on the increase throughout the span of intervocalic nasals in these structures, and hence the pitch peak was delayed to the endpoint of nasal.

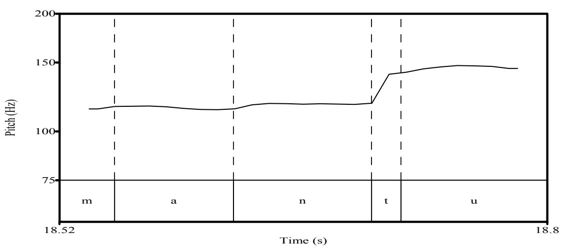
4. Tonal Alignment

4.1. Tonal alignment of the CVNCV structure

This section deals with the alignment of the target tones in the CVNCV structure when they are anchored on the segmental string. Focus is laid on displacement of the accentual peak to the postvocalic nasals [m, n, ŋ]. We first begin with the LH class. Consider the following F0 pitch excursions[6].



a. [kamca] ‘potato’

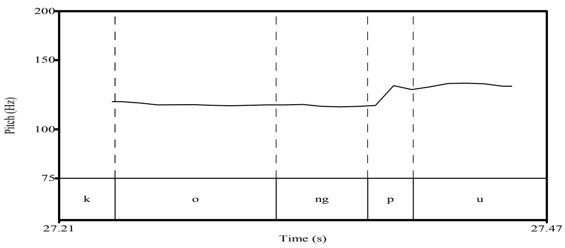


b. [mantu] ‘dumpling’

4) Most of the test words were designed to end in an open syllable in word-final position in order to focus on the tonal alignment of the first vowel and its postvocalic nasal(s).

5) The temporal distance of the pitch peak delay was not measured from the H target of the LH class; nor was it measured from the second H target of the HH class. These H targets in the word-final syllable are controlled not to be displaced in this experiment.

6) For the sake of notational convenience, the IPA symbols are not strictly employed in the representation of the textgrid of the F0 pitch excursions throughout this paper.

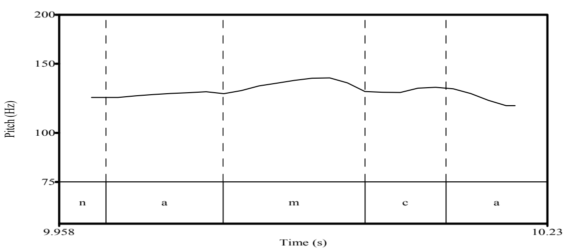


c. [koŋpu] ‘study’

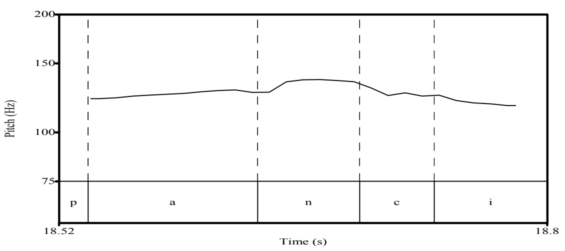
Fig. 1. Pitch excursion of LH class in CVNCV structure

In all the F0 pitch excursions in fig. 1, the L target is sustained to the tautosyllabic nasal past the nucleus vowel, stretching a low flat tone to the end of the nasal. After the postvocalic nasal, there is a sharp rise during the onset consonant of the second syllable. According to table 1, the average F0 value of the initial vowel in the LH class of the CVNCV structure is 110.0 Hz, and continues to rise to 114.0 Hz during the following nasal. However, the F0 pitch sharply rises during the prevocalic obstruent and reaches 139.0 Hz in the word-final vowel. This indicates that postvocalic nasals do not participate in tonal interpolation between the L and the H targets of their neighboring vowels, and that tonal transition from the L to the H is virtually restricted to the prevocalic obstruent. It is also worthwhile to note that the H target of the second vowel is sustained for a significant part of the vowel. The F0 pitch excursion of this contour is common to all the test words across the speakers and regardless of the place feature of the coda nasals.

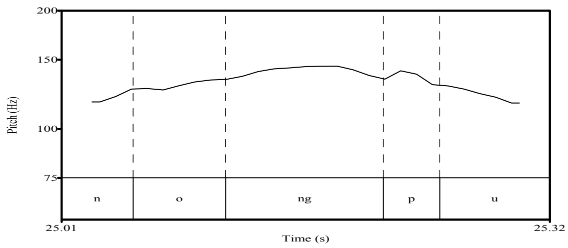
We now turn to the tonal alignment of the HL class in the CVNCV structure. Consider the following F0 pitch excursions:



a. [namca] ‘man’



b. [panci] ‘ring’



c. [noŋpu] ‘farmer’

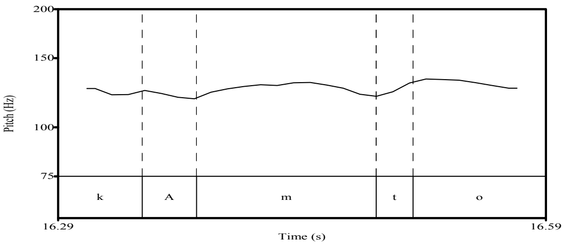
Fig. 2. Pitch excursion of HL class in CVNCV structure

Note that in all the F0 pitch excursions in fig. 2, the pitch peak of the H target on the initial syllable is systematically displaced to the right of the nucleus vowel, and that the peak is delayed to the following nasal. As shown in table 3, the average duration of the coda nasal in the HL class of the CVNCV syllable is as long as 86.0 ms, and the average temporal distance between the onset of the nasal and the F0 pitch peak of the H target is 47.6 ms. Derivable from these two measurements is the ratio of the pitch peak delay, which amounts to 56%. This indicates that the peak of the H target in the HL class is realized around midpoint in the total duration of the nasal. The ratio of the peak delay in tonal alignment of the HL class turned out to range from 44% to 71% among the three speakers (cf. table 3).

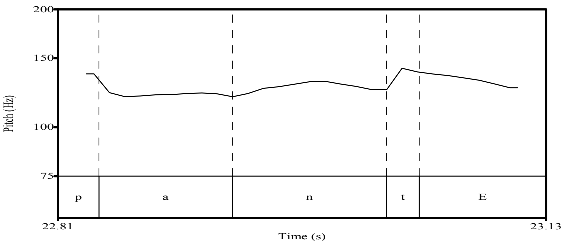
From the perspective of scaling on the vertical axis, the increase of the F0 pitch in a given duration in the postvocalic nasal is greater than that in the prenasal vowel. That is, the slope of the F0 pitch curve during the postvocalic nasal is steeper than the one during the prenasal vowel. The contour of the pitch excursion shows a step-like gradual rise from the onset of the nasal, although the rise of the F0 pitch contour starts in advance from around the midpoint of the prenasal vowel. The average F0 pitch value of the initial vowel in this tonal class is 124.3 Hz, while that of the postvocalic nasal is as high as 141.0 Hz (cf. table 1). By the time the F0 pitch curve reaches the onset of the final vowel, the pitch of the L target decreases to 126.3 Hz, sharply falling thereafter.

We now turn to the tonal alignment of the HH class in the CVNCV structure. Given below are the F0 pitch excursions of the words [kə:mto], [pa:ntɛ], and [na:ŋpi][7]:

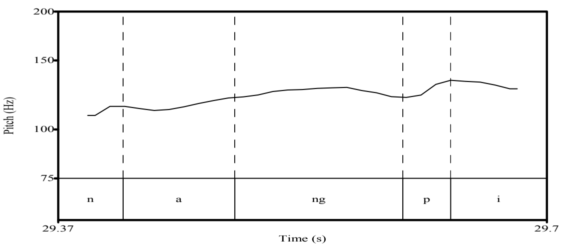
7) The initial syllable tends to have a long vowel in bisyllabic words of the HH class.



a. [kə:mto] ‘fencing’



b. [pa:ntɛ] ‘opposition’



c. [na:ŋpi] ‘waste’

Fig. 3 Pitch excursion of HH class in CVNCV structure

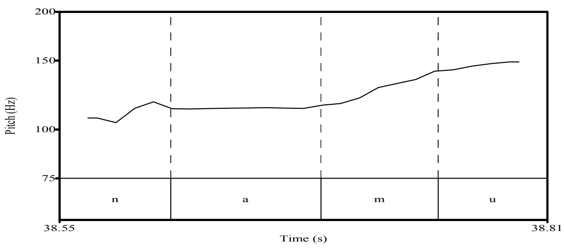
The pitch excursion of bisyllabic words in the HH class shows two pitch peaks where the F0 pitch peak of the second syllable is slightly higher than that of the initial syllable. The average F0 value of the initial vowel in this tonal class is 119.0 Hz, while that of the postvocalic nasal reaches 134.3 Hz, approximately 15 Hz higher than that of the initial vowel (cf. table 1). After a dip toward the end of the postvocalic nasal, the F0 pitch sharply rises during the following obstruent and reaches 141.0 Hz at the onset of the second vowel, approximately 7 Hz higher than the first pitch peak. Given the tonal scaling of two H targets within a word, where the second pitch peak is higher than the first, the H target of the second syllable can be defined as the pitch peak of bisyllabic words in the HH class. The F0 pitch excursion of the second syllable in the HH class makes a parallel to the one in the LH class in that the obstruent serves as the locus of a steep rise to form a pitch peak on the following nucleus vowel. Unlike the high flat tone on the nucleus vowel for the H target of the LH class, however, the pitch peak of the nucleus vowel for the second H target of the HH class sharply falls after reaching the pitch peak at the onset of the second vowel. The steep decrease of the H target on the second vowel is comparable to the shape of the pitch curve implemented for the L target of the HL class (cf. fig. 2).

In the tonal alignment of the HH class, the F0 pitch peak of the H target of the initial syllable is systematically displaced to the right of the nucleus vowel and is delayed to the following nasal, hence making a parallel to the tonal alignment of the H target in the HL class. In displacement of the pitch peak in the initial syllable, the average temporal distance between the onset of the nasal and the F0 pitch peak of the H target is 69.2 ms, while the average duration of the coda nasal in the HH class of the CVNCV syllable is as long as 100.9 ms (cf. table 3). Derivable from these two measurements of duration is the ratio of the pitch peak delay: it turned out to be 70%, ranging from 66% to 78% among the three speakers. The ratio of the pitch peak delay turned out to be greater in the HH class, compared with the HL class. Not only the raw peak delay but also the relative peak delay turned out to be greater in the HH class, presumably due to the fact that bisyllabic words in this class have a strong tendency to have a long vowel in the initial syllable.

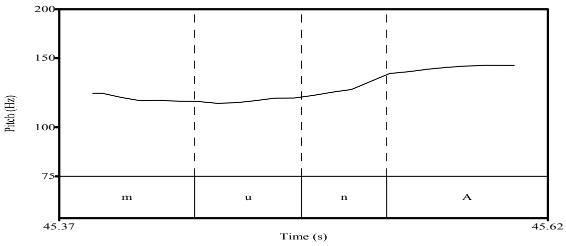
4.2. Tonal alignment of the CVNV structure

We now turn to the tonal alignment of the CVNV structure to investigate various patterns of the alignment of the accentual peaks in the context of intervocalic nasals [m, n, ŋ]. When nasals are in an intervocalic environment, [m] and [n] function as onset of the following syllable (CV.m/nV), whereas the velar nasal [ŋ] functions as coda of the preceding syllable (CVŋ.V) due to a constraint on syllable structure in Korean. The structural asymmetry provides a testing ground to see if a phonology-based position in the syllable has an effect on patterns of the tonal alignment. First examined is the tonal alignment of the LH class.

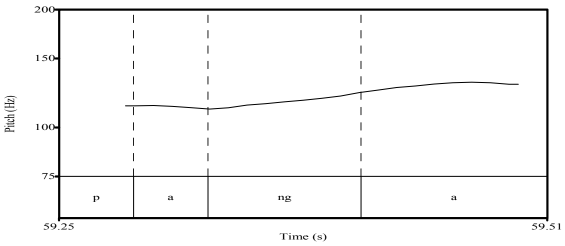
The LH class arises when the accentual peak occurs on the second syllable of bisyllabic words. Consider the following F0 pitch excursions in the intervocalic nasal and two flanking vowels.



a. [namu] ‘tree’



b. [munə] ‘octopus’



c. [paŋa] ‘mill

Fig. 4. Pitch excursion of LH class in CVNV structure

The low tone at the onset of the nasal continues to rise to the end of the nasal, shaping a gradual step-like pitch increase. Thus, intervocalic nasals are tonally interpolated between the L and the H targets regardless of the place feature of the nasals. According to the measurements in table 1, the average F0 value of the first vowel is 110.2 Hz and that of the second vowel 139.6 Hz, with the intervening nasal rising to 132.3 Hz. This shows that tonal interpolation takes place whenever there is a postvocalic nasal, to which the pitch peak of the H target can be displaced regardless of its intrasyllabic constituency. It is also noteworthy that the H target of the second syllable is not aligned at the onset of the nucleus vowel; the pitch peak is displaced to some point in the latter half of the vowel duration. Thus, the shape of the F0 contour of the second vowel is parallel to the one in the LH class of the CVNCV structure, where the H target is retained in a high flat tone throughout the second vowel (cf. fig. 1).

While all three speakers showed a uniform pitch excursion at the tonal interpolation of anterior nasals [m, n], variation was observed by two speakers in the case of velar nasal [ŋ]. Consider the following F0 pitch excursion:

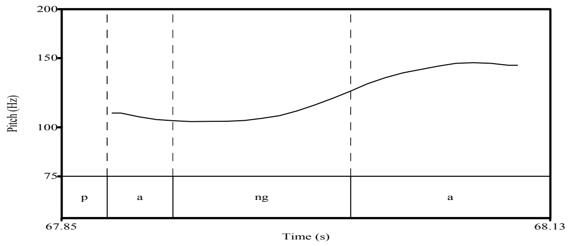
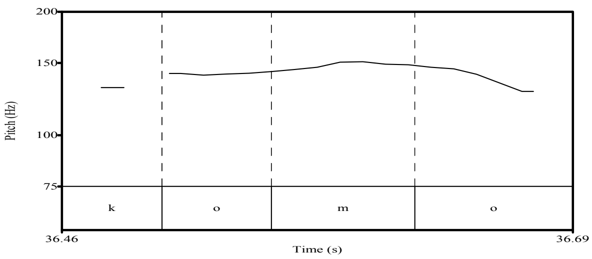


Fig. 5. Alternating pitch excursion of [paŋa] ‘mill’

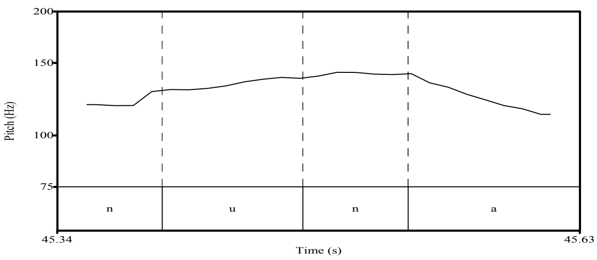
In fig. 5, the low flat tone of the initial syllable is carried over to a midpoint in the tautosyllabic velar nasal, and it is only the latter half of the nasal [ŋ] that participates in tonal interpolation between two targets. This pattern is divergent from the shape of the F0 pitch excursion in fig. 4, where intervocalic nasals fully participate in tonal interpolation for the total duration of the nasal. The extension of the L target to the postvocalic nasal is interpreted as a reflection of tautosyllabicity of the velar nasal to its preceding vowel. This pattern is similar to the F0 contour of the postvocalic coda nasals in the LH class of the CVNCV structure (cf. fig. 1).

Speaker-dependent variation in the tonal alignment can be accounted for by the asymmetry in the prosodic structure of intervocalic nasals. The asymmetry of the F0 pitch excursion between [m, n] and [ŋ] is attributed to positional difference in the syllable structure. Nasals [m, n] participate in tonal interpolation to reach the H target of their tautosyllabic syllable, departing from the L target of their preceding heterosyllabic vowel; in the case of the velar nasal [ŋ], the L target of the initial syllable is sustained to the right of the nucleus vowel since it is tautosyllabic to its preceding vowel. Thus, disparity in the tonal specification of nasal [ŋ] is accounted for as a function of sensitivity to the prosodic structure. For some speakers, all three nasals pattern together in intervocalic environment with respect to the tonal alignment. Tonal specification of three nasals is commonly supplied by interpolation between the L and the H targets of their flanking vowels regardless of their place feature. For others, prosodic information plays a role in the alignment of the accentual peaks, and as a consequence, intervocalic nasals diverge on the pattern of the tonal alignment, depending on whether the nasal constitutes tautosyllabicity to the preceding or the following vowel. Tautosyllabicity, in turn, is determined by segmental composition of the nasal. In any case, tonal specification of nasals [m, n] is invariably supplied by tonal interpolation since they are not tautosyllabic to the preceding vowel.

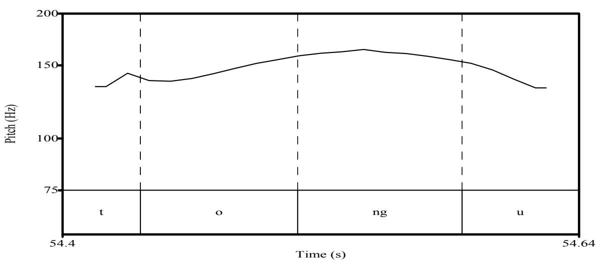
We now turn to the tonal alignment of the HL class. As the HL class arises in bisyllabic words when the pitch accent falls on the initial syllable, the pitch peak is expected to be realized on the nucleus vowel. Consider the following F0 pitch excursion:



a. [komo] 'aunt'



b. [nuna] 'sister'



c. [toŋu] 'man's name'

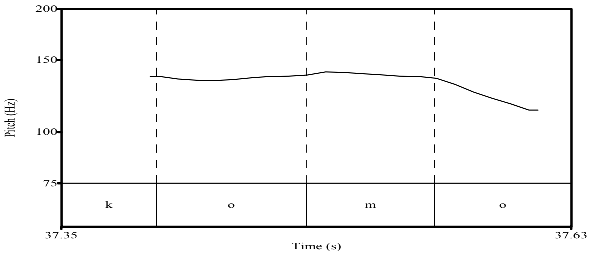
Fig. 6. Pitch excursion of HL class in CVNV structure

In the pitch excursions above, the F0 pitch peak is displaced to the right of the nucleus vowel and is delayed to the intervocalic nasals, regardless of whether they are tautosyllabic to the preceding or the following vowel. This is shown by the measurements given in table 1: the average F0 value of the initial vowel is 138.1 Hz, while that of the intervocalic nasal rises to 149.6 Hz. The average F0 value of the second vowel is 143.6 Hz at its highest point, i.e. at the onset of the vowel, but it sharply falls thereafter to implement the L target of the second syllable. The degree of the pitch peak delay within intervocalic nasal turned out to be variable among the three nasals and also among the speakers.

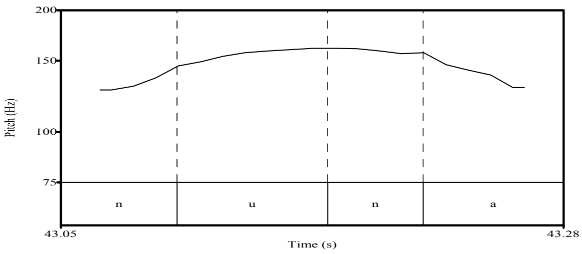
The fact that three intervocalic nasals pattern together in the tonal alignment in fig. 6 is similar to the alignment of the LH class illustrated in fig. 4. Note from fig. 4 that all three nasals participated in tonal interpolation between the L and the H targets in the CVNV structure. If the HL class patterns essentially in the same way as the tonal alignment of the LH class, nasals in fig. 6 are expected to participate in tonal interpolation as well. Instead of interpolation between the H and the L targets, however, the F0 pitch peak is displaced to the right of the nucleus vowel and is delayed to the intervocalic nasal. Therefore, it is impossible for intervocalic nasals to fully participate in tonal interpolation. It is only in the remaining part of the nasal after the pitch peak that the intervocalic nasals participate in tonal interpolation. Thus, the intervocalic nasal is predicted not to take part in tonal interpolation, if the pitch peak is maximally displaced to the endpoint of the nasal. This is what happens in the tonal alignment of [n] in [nuna] in fig. 6.

The shape of the pitch excursion of the HL class of the CVNV structure in fig. 6 provides supporting evidence to the hypothesis that tonal alignment is implemented by simply parsing the segmental string without reference to the prosodic structure, since the pitch peak of the H target is delayed to the right of the nucleus vowel regardless of whether the intervocalic nasal is tautosyllabic to the preceding vowel or not. In other words, the intervocalic nasals [m, n] as well as velar nasal [ŋ] serve as the site for the pitch peak displacement; tonal interpolation, if any, is only secondary to displacement of the pitch peak.

Displacement of the pitch peak to the right of the nucleus vowel in the HL class, however, remains a puzzle in the case of intervocalic nasals [m, n]. These nasals constitute onsets of the following vowels in the CVNV structure, hence heterosyllabic to the preceding vowel. Since these nasals form a functional unit with their following vowel, they are expected to participate in tonal interpolation to implement the L target of the following syllable. In fact, intervocalic nasals [m, n] show speaker-dependent variation with respect to tonal displacement, while all three speakers showed a uniform shape of the F0 contour representing tonal displacement to intervocalic velar nasal [ŋ]. The alternating patterns of the F0 contour for two nasals [m, n] are characterized by interpolation between the H and the L targets, as shown in the following pitch excursion.



a. [komo] ‘aunt’

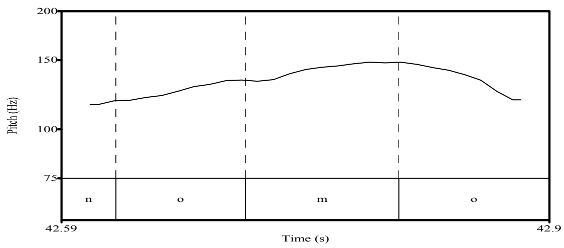


b. [nuna] ‘sister’

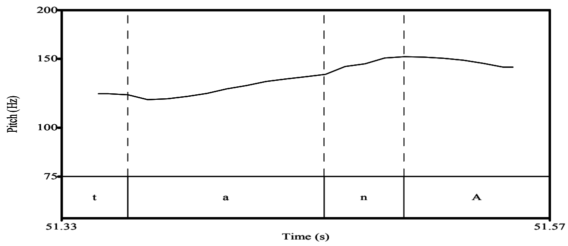
Fig. 7. Alternating pattern of pitch excursion of HL class

The F0 pitch excursions in fig. 7, unlike their counterparts in fig. 6, do not show tonal displacement to the right of the nucleus vowel; rather, the F0 pitch peak occurs at the endpoint of the nucleus vowel. As a consequence, intervocalic nasals fully participate in tonal interpolation between the H and the L targets of their flanking vowels. For those speakers whose tonal alignment takes the pattern as in fig. 7, the pattern of the tonal alignment for [m, n] diverges from the pattern for nasal [ŋ] since the velar nasal [ŋ] invariably participates in tonal displacement. Nasals [m, n] are also specified by tonal displacement in the case of the non-structure-sensitive parsing (cf. fig.6). However, under the structure-sensitive parsing, they participate in tonal interpolation since they are heterosyllabic to the preceding vowel. Therefore, disparity in the patterns of the tonal alignment is an artifact resulting from the asymmetry among nasals with respect to their position in the prosodic structure. To summarize, it is the velar nasal [ŋ] in the case of the LH class, and nasals [m, n] in the case of the HL class, that show speaker-dependent variation. In other words, nasals [m, n] and [ŋ] show a uniform pattern of the alignment in the LH and the HL classes respectively.

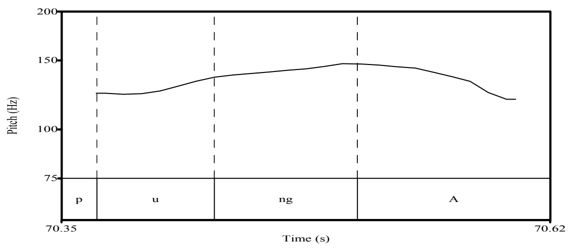
We now turn to the HH class of the CVNV structure. Consider the following F0 pitch excursions:



a. [no:mo] ‘aged mother’



b. [ta:nə] ‘word’



c. [pu:ŋə] ‘carp’

Fig. 8. Pitch excursion of HH class in CVNV structure

From the F0 pitch excursions above, two observations can be made: first, the pitch peak of the first syllable is uniformly displaced to the postvocalic nasal. The average pitch value of the first vowel was 124.0 Hz but that of the following nasal rose to 141.6 Hz (cf. table 1). Displacement of the pitch peak to the right of the nucleus vowel takes place in the HH class regardless of the place feature of the intervocalic nasal. Thus, it patterns with the pitch peak delay of the H target to the subsequent postvocalic nasal in the HL class of the CVNCV structure. Note also that in the non-structure-sensitive parsing of the HL class of the CVNV structure (cf. fig. 6), the pitch peak is displaced to the right of the nucleus vowel regardless of the segmental composition of the nasal. The fact that the first H target of the HH class in the CVNV structure does not fail to be displaced provides supporting evidence to the hypothesis that the tonal alignment is not sensitive to the prosodic structure. What counts in tonal mapping of the segmental string is presence of a nasal as a postvocalic segment, onto which the pitch peak is displaced.

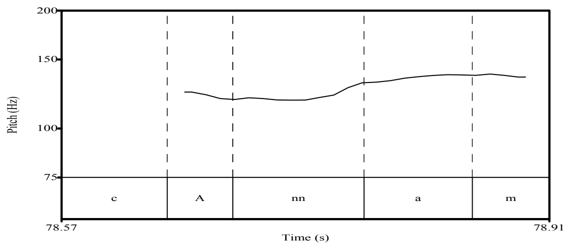
Secondly, the pitch peak of the H target of the first syllable coincides with that of the second syllable. Note from table 1 that the average pitch value of the intervocalic nasal representing 141.6 Hz continues to rise to 144.6 Hz in the second vowel. What is peculiar about the tonal alignment of the initial H target in this class is that the F0 pitch peak is delayed to the endpoint of the intervocalic nasal. In conjunction with the fact that the H target of the second syllable is aligned at an earlier point in the nucleus vowel, this has an effect on the shape of the pitch excursion of the HH class, namely that there is no pitch fall between two H targets. Thus, the pitch peak of the first syllable is realized flush against that of the following syllable. As a consequence, the F0 pitch peaks of the two H targets in the HH class converge onto a single point in the segmental string of the CVNV structure, resulting in a single pitch peak. This contrasts with the HH class of the CVNCV structure, where the H target of the initial syllable is delayed to its following nasal, but not to the endpoint, and the H target of the second syllable is independently realized on the second syllable in a higher pitch than that of the initial syllable, hence resulting in two pitch peaks (cf. fig. 3).

As for a single pitch peak in the HH class, an alternative is to account for it as an artifact of tonal interpolation between two H targets. Under this view, the pitch peak of the first H target takes place at the end of the first vowel, while that of the second H target takes place at the beginning of the second vowel. It follows then that tonal specification of an intervening nasal is supplied by interpolation between two H targets of the flanking vowels.

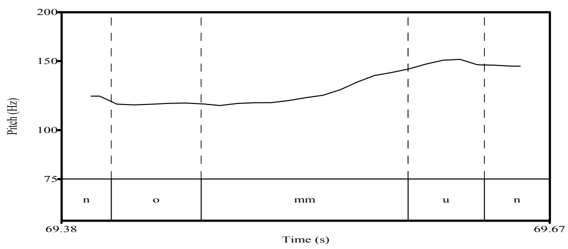
4.3. Tonal alignment of the CVNNV structure

We now turn to the CVNNV structure, where two nasals appear in a row in an intervocalic environment. Due to the phonotactic constraint on coda nasal and anticipatory place assimilation between two nasals, intervocalic nasal sequences are limited to five types: [nn], [mm], [mn], [ŋm], and [ŋn]. The average duration of these nasal sequences is as long as 125.5 ms, while that of nasals in the CVNCV and the CVNV structures is 92.4 ms and 70.5 ms respectively (cf. table 2). In this section we investigate the way in which the F0 pitch excursion varies in the tonal alignment of the CVNNV structure, depending on the tonal class and also on the types of nasal sequences. In the following figures of the F0 pitch excursion, two adjacent nasals are separately marked in the textgrid when they are distinguishable from each other based on the soundwave and the spectrogram; otherwise, they are represented in a single cell. First dealt with is the tonal alignment of the LH class.

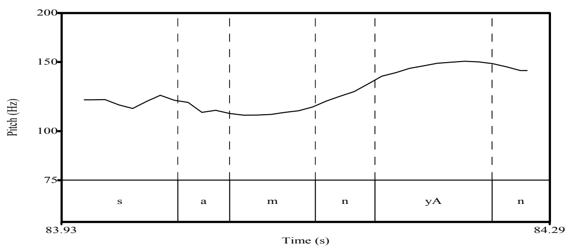
The LH class arises when the accentual peak occurs on the second syllable of bisyllabic words. Thus, the intervocalic nasals take place between the L and the H targets in that order. Consider the following pitch excursions involving five types of nasal sequences.



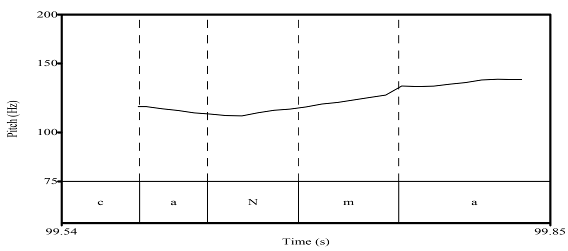
a. [cənnam] ‘name of a province’



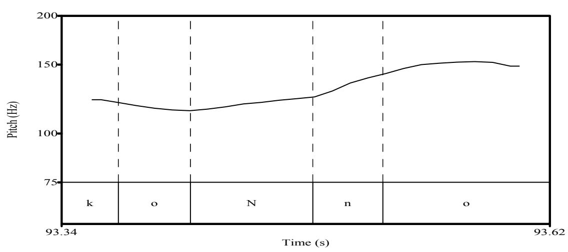
b. [nommun] (/nonmun/) ‘article’



c. [samnyən] ‘three years’



d. [caŋma] ‘rainy season’



e. [koŋno] (/koŋlo/) ‘merit’

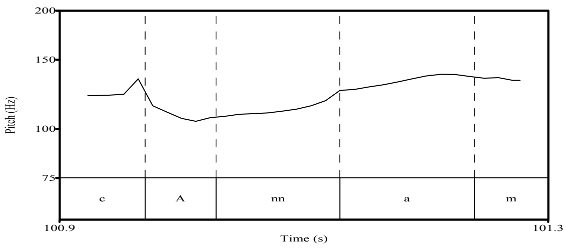
Fig. 9. Pitch excursion of LH class in CVNNV structure

Two observations can be made from the pitch excursions above[8]. First, in all the pitch excursions, the L target of the first syllable is extended to the right of the nucleus vowel and is implemented on the postvocalic nasal (N_1) as well: the low tone is realized on the total duration of the first nasal in the case of surface geminates [nn] and [mm], while it is realized on the partial duration of the first nasal in the case of nasal sequences [mn], [ŋm] and [ŋn][9]. Extension of the L target to the postvocalic nasal (N_1) is regarded as a reflection of the prosodic constituency, namely that N_1 is tautosyllabic to the preceding vowel.

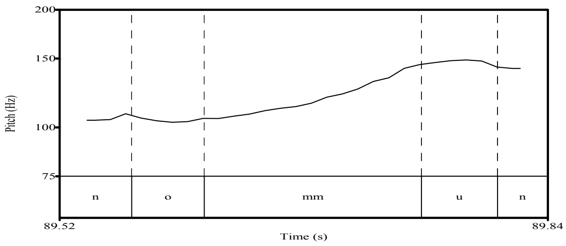
Secondly, the intervocalic nasal sequence takes part in tonal interpolation between the L and the H targets of the flanking vowels. This is shown in the measurements given in table 1: The average pitch value of the first vowel is 113.1 Hz, while that of the second vowel 142.1 Hz. Between these two targets, the average pitch value of the nasal sequence rises to 127.6 Hz. In all types of nasal sequences, it is the prevocalic nasal (N_2) in the nasal sequence that primarily takes part in tonal interpolation between the L and the H targets[10]. In the tonal alignment, the LH class of the CVN_1N_2V structure patterns with its counterpart in the CVNCV structure in that the L target of the first syllable is implemented on the nucleus vowel and is extended to its tautosyllabic nasal (N_1), while the prevocalic nasal (N_2) or obstruent, takes part in tonal interpolation due to its tautosyllabicity to the following vowel.

It is noteworthy that patterns of the tonal alignment of the LH class in the CVNNV structure diverge according to the nature of the nasal cluster: the L target of the first syllable is realized for a longer period of the postvocalic nasal when the nasal cluster is composed of identical nasals, compared with when they are composed of different nasals ([cənnam] vs. [caŋma] in fig. 9). This suggests that segmental composition of the nasal sequence has an effect on the shape of the F0 contour.

Patterns of the tonal alignment also vary as a function of the geminate nature of nasals in a sequence. Consider the following pitch excursions of nasal geminates spoken by one speaker:



a. [cənnam] ‘name of a province’



b. [nommun] (/nonmun/) ‘article’

Fig.10. Pitch excursion of identical nasals in LH class

The pitch excursions above consistently show a gradual step-like increase of the F0 pitch during the total period of the intervocalic nasal sequence, without extension of the L target to the postvocalic nasal (N_1). In other words, the nasal sequence fully participates in tonal interpolation between the L and the H targets of the flanking nucleus vowels. This pattern contrasts with the F0 pitch excursion in fig. 9, where the L target is sustained beyond the nucleus vowel to its postvocalic nasal.

Expansion of tonal interpolation to the total duration of the nasal sequence is attributed to longer duration of oral closure in considerably overlapping gestures for the nasal geminate, instead of two repeated gestures of closure and release. In this respect, the nasal geminate behaves like a singleton in the phonetic implementation of the tonal alignment, although two identical nasals are phonologically heterosyllabic. In other words, a nasal sequence composed of identical nasals counts as a single nasal unit, which in turn constitutes the onset of the following syllable. Therefore, the shape of the F0 contour demonstrating full-scale tonal interpolation is interpreted as a reflection of the phonetic readjustment. It follows then that the LH class of the CVNNV structure is equivalent to its counterpart in the CVNV structure with respect to the tonal alignment. The pitch excursion of the nasal sequence in fig. 10 patterns with that of the intervocalic nasal in fig. 4 with respect to the major effect

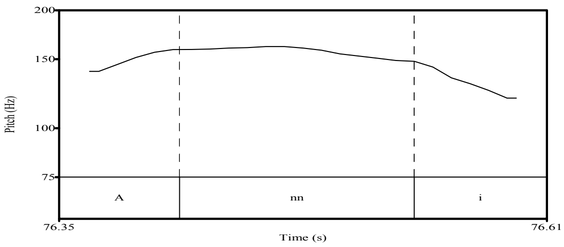
8) Absence of the pitch peak displacement to the word-final nasal in the cases of [cənnam], [nommun], and [samnyən] is attributed to resyllabification of the word-final nasal into onset. Due to the vowel [i] in the carrier sentence /-ita/, word-final nasal is resyllabified as onset of the following syllable, which is associated with the L.

9) It is assumed here that a sharp rise takes place in the second nasal of the nasal geminates [nn] and [mm], although the division between two identical nasals is not clear on the spectrogram. Duration of the stable pitch period of the first nasal representing the low tone varies among three forms of [samnyən], [caŋma], and [koŋno], and also among three speakers.

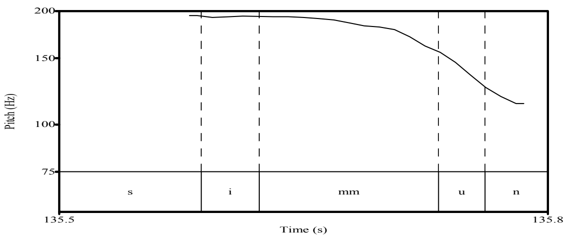
10) The postvocalic nasal (N_1) in the nasal sequence in [samnyən], [caŋma], and [koŋno] partially takes part in tonal interpolation, as indicated by the gentle slope of the F0 pitch curve toward the end of the postvocalic nasal (N_1) but before the prevocalic nasal (N_2).

of tonal interpolation, whereas the one in fig. 9 patterns with the one in fig. 5 with respect to extension of the low tone to postvocalic nasal.

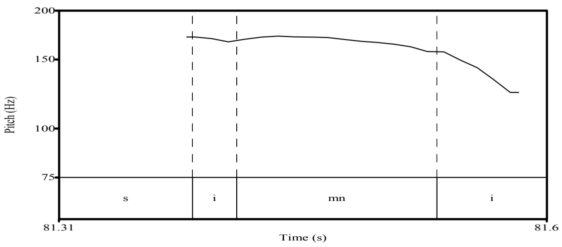
We now turn to the tonal alignment of the HL class, where the pitch accent falls on the initial syllable. Consider the following pitch excursions:



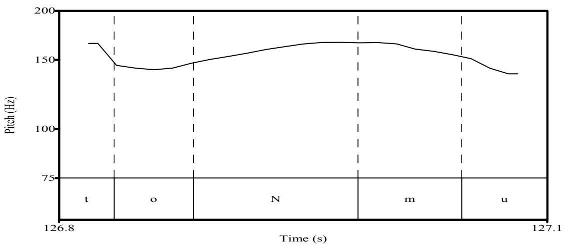
a. [ənni] ‘sister’



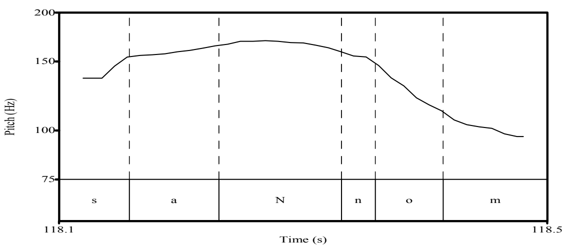
b. [simmun] (/simmun/) ‘interrogation’



c. [simni] (/sim-li/) ‘psychology’



d. [toŋmu] ‘friend’



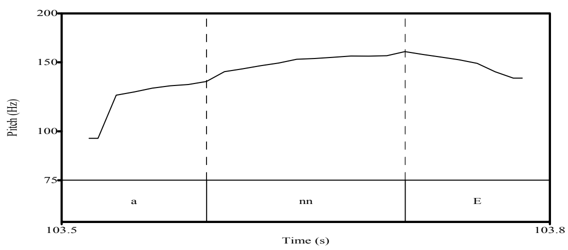
e. [saŋnom] ‘low man’

Fig. 11. Pitch excursion of HL class in CVNNV structure

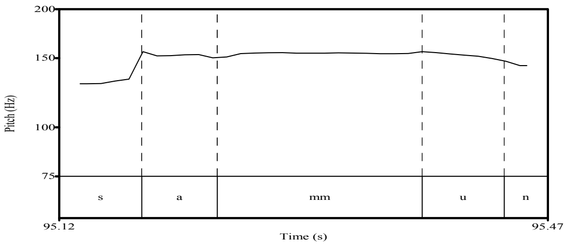
Regardless of the segmental composition in nasal sequences, the H target of the initial syllable is displaced to the right of the nucleus vowel and the F0 pitch peak is delayed to the postvocalic nasal, although there is variation in the degree of the pitch peak delay. The average pitch value of the intervocalic nasal sequence is 166.6 Hz, which is higher than that of the first vowel representing 152.0 Hz. The average pitch value of the following vowel decreases to 143.3 Hz at its onset, sharply falling thereafter toward the end of the word. Displacement of the pitch peak to the postvocalic nasal in the HL class is the shape of the F0 contour that has been consistently observed in the tonal alignment of the CVNCV and the CVNV structures. It is noteworthy that the temporal distance between the onset of the nasal and the pitch peak tends to be longer in nasal sequences involving [ŋ] as in [toŋmu] and [saŋnom], compared with other types of nasal sequences in fig. 11. The greater ratio of the pitch peak delay in the nasal [ŋ] is interpreted as a reflection of its prime candidacy for coda position, which creates a stronger functional tie with its preceding vowel, when compared with other nasals [m, n]. The gradience in the degree of the pitch peak delay is comparable to the tonal alignment of the HL class of the CVNV structure, where full-scale tonal interpolation is not available in the case of [ŋ], although other nasals show variation between partial and full-scale tonal interpolation (cf. fig. 6-7).

The prevocalic nasal (N_2) in the nasal sequence does not take part in tonal displacement of the H target of the initial syllable; rather, it participates in tonal interpolation between the H and the L targets of their neighboring vowels. Thus, the second nasal in the nasal sequence serves as the site for tonal interpolation for both the LH and the HL classes, although opposite in their F0 pitch contours. This leads to a generalization, namely that two nasals in the nasal sequence play different roles in the tonal alignment: N_1 for extension of the L target or tonal displacement of the H target, whereas N_2 invariably for tonal interpolation.

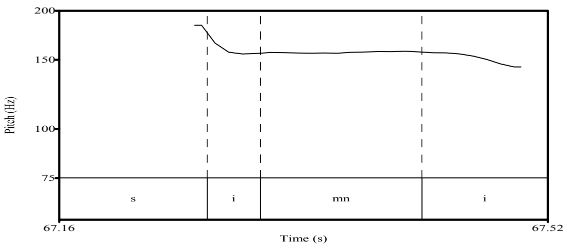
We now turn to the tonal alignment of the HH class in the CVNNV structure. Consider the following F0 pitch excursions.



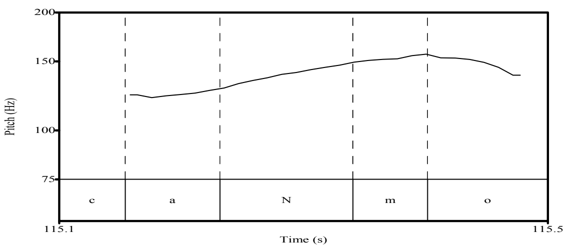
a. [aːnnɛ] ‘guide’



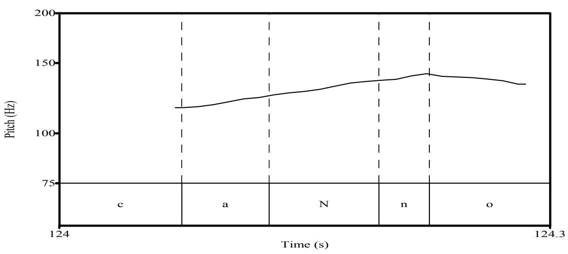
b. [sa:mmun] (/sa:nmun/) ‘prose’



c. [simni] (/sip-li/) ‘ten miles’



d. [ca:ŋmo] ‘wife’s mother’



e. [ca:ŋno] (/ca:ŋlo/) ‘elder’

Fig. 12. Pitch excursion of HH class in CVNNV structure

In all the pitch excursions above, there is only a single pitch peak in the F0 pitch excursion of the HH class in the CVNNV structure. This pattern parallels its counterpart in the CVNV structure; however, it contrasts with two pitch peaks in its counterpart in the CVNCV structure. The HH class of the CVNNV structure also patterns with that of the CVNV structure with respect to the locus of the pitch peak, which takes place at the juncture of the prevocalic nasal (N2) and its following vowel.

The H target of the initial syllable is tonally implemented in two ways: one is to have the initial H target realized in the nucleus vowel and sustained to the end of the nasal sequence or even to a later point in the following vowel, as shown in the nasal sequences of [mm] and [mn]. In this case, the F0 pitch excursion continues to maintain a high flat tone until it starts to fall. The other is to have the H target of the initial syllable delayed to the right of the nucleus vowel. When the F0 pitch peak is displaced, however, it is displaced not just to the first nasal N_1 but to the endpoint of the nasal sequence in the CVNNV structure. Thus, the pitch peak of the initial H target is delayed to the endpoint of the nasal sequence flush against the onset of the following vowel, where another H target is anchored. As a result, two pitch peaks converge onto a single point, namely between the end of the prevocalic nasal N_2 and the onset of the following vowel. Thus, the locus of the pitch peak in this class essentially coincides with that of the HH class in the CVNV structure.

As suggested in discussion of the HH class of the CVNV structure, an alternative account of a single pitch peak in the pitch excursions in fig. 12 relies on tonal interpolation between two H targets. The nasal sequence between two vowels is tonally specified by interpolation between two H targets, one taking place at the end of the first vowel and the other at the beginning of the second vowel.

5. Conclusion

Investigating patterns of the alignment of the accentual peaks in bisyllabic words of the CVNCV, CVNV and CVNNV structures in NKK, this study accounted for the way in which the tonal targets are aligned and tonal specifications of intervening nasals are supplied in each class of the LH, HL, and HH. Tonal specification of nasals in various environments is accounted for in terms of extension of the low tone, displacement of the pitch peak and tonal interpolation, depending on the type of syllable structure and of the tonal class. The results provide preliminary evidence that the categorical alignment of the tonal targets is implemented by checking the linear precedence of segments on the string, without reference to syllable structure. However, speaker-dependent variations in the tonal alignment are represented as a function of syllable structure, which in turn is correlated with segmental composition. Thus, the prosodic structure turned out to play a significant role in determining the shape of the F0 contour.

In the CVNCV structure where the nasal is tautosyllabic to its preceding vowel, the tonal alignment of the LH class is characterized by extension of the L target to the postvocalic nasal. The H target of the HL class is displaced to the right of the nucleus vowel, and hence the pitch peak is delayed to the postvocalic nasal. The HH class shares with the HL class displacement of the H target to the postvocalic nasal. Unlike the postvocalic nasal whose tonal specification is dependent on the tonal class, a prevocalic obstruent participates in interpolation in any tonal class.

The tonal alignment of the CVNNV structure generally patterns with its counterpart in the CVNCV structure. In the LH class, tonal specification of postvocalic nasal (N_1) is supplied by extension of the L target in the preceding vowel, whereas in the HL class, it is supplied by displacement of the pitch peak to the right of the nucleus vowel. In both the LH and the HL classes, prevocalic nasal (N_2) participates in tonal interpolation between two opposite targets. In the LH class, however, nasal geminates optionally function as a single nasal, and their tonal specification is supplied exclusively by interpolation, without resorting to extension of the L target. This pattern of the alignment parallels its counterpart in the CVNV structure. Tonal specification of the nasal sequence in the HH class can be interpreted either as an extreme case of tonal displacement or as an interpolation between two H targets. The latter may be a more legitimate interpretation since the H tone is displaced to the extent that the pitch peak occurs at the juncture of the nasal and the postnasal vowel. The extreme displacement can be viewed as an interpolation between the two H targets since there is no dip between two pitch peaks, hence leading to a single pitch peak for this class. In the absence of crucial evidence for one or the other, however, we leave this issue for future research. Tonal specifications of segments intervening between two tonal targets can be summarized as follows:

	LH	HL	HH
CVNCV	L-ext & Interpl	Displ & Interpl	Displ & Interpl
CVNNV	(L-ext) & Interpl	Displ & Interpl	Interpl (=Displ)

Table 5. Patterns of tonal specification

In the CVNV structure, patterns of the tonal alignment diverge depending on whether the alignment is sensitive to the prosodic structure or not. When the tonal alignment is not sensitive to the intrasyllabic constituency of an intervocalic nasal, tonal specification of the intervocalic nasal is supplied by interpolation in the case of the LH class, and by the pitch peak displacement, in conjunction with interpolation, in the case of the HL class. In the HH class the intervocalic nasal is also specified by displacement of the pitch peak. As in the CVNNV structure, tonal specification of the nasal in the HH class can be equally accounted for by interpolation between two H targets, since the pitch peak is displaced to the endpoint of the nasal.

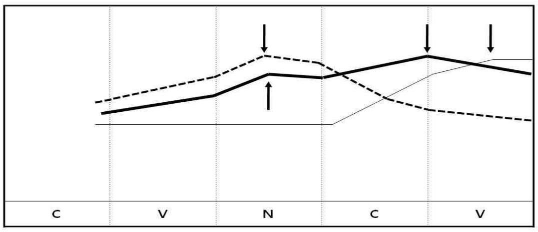
On the other hand, when the tonal alignment is sensitive to the prosodic structure, patterns of the tonal alignment diverge as a function of syllable structure correlated with featural composition of the nasal, except for the HH class. The asymmetry in the prosodic structure, namely, that nasals [m, n] are tautosyllabic to the following vowel, whereas the velar nasal [ŋ] is to the preceding vowel, leads to the asymmetry in the tonal alignment. In the case of the LH class, tautosyllabicity of [ŋ] to the preceding vowel affects the shape of the F0 contour in such a way that the L target of the first syllable is extended to its tautosyllabic velar nasal. In the HL class, tonal specification of intervocalic nasals [m, n] is supplied by interpolation since they are tautosyllabic to the following vowel in the CVNV structure. Thus, for the LH class it is the nasals [m, n] that are uniformly specified by tonal interpolation, whereas for the HL class it is the nasal [ŋ] that is uniformly specified by displacement of the pitch peak.

Taken together, tonal specification in the CVNV structure is supplied as follows, depending on sensitivity to the prosodic structure:

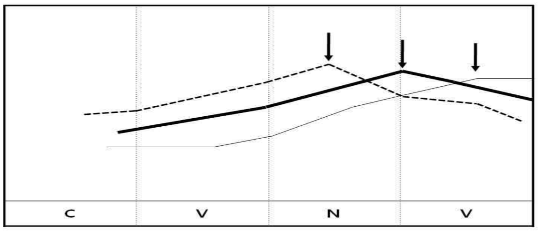
	Non-structure-sensitive	Structure-sensitive	
	[m, n, ŋ]	[m, n]	[ŋ]
LH	Interpl	Interpl	L-ext
HL	Displ (& Interpl)	Interpl	Displ (& Interpl)
HH	Interpl (=Displ)	---	---

Table 6. Patterns of tonal specification of CVNV structure

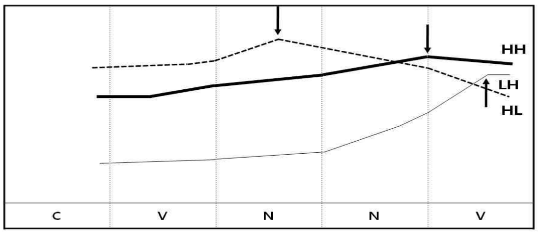
Finally, it is noteworthy that for each type of tonal class, the locus of the pitch peak coincides across three types of the structure (except for the HH class of the CVNCV structure due to two pitch peaks). Regardless of the type of the structure, the pitch peak takes place during the second vowel in the LH class; during the postvocalic nasal (or N_1) in the HL class; and at the juncture of the prevocalic nasal and the second vowel in the HH class. This is schematically illustrated as follows:



a. CVNCV structure



b. CVNV structure



c. CVNNV structure

Fig. 13. Schematic representation of F0 peak loci

This result provides supporting evidence for consistency in the tonal alignment under changes in syllable structure or speech rate (Xu, 1998; Ladd et al., 1999). The convergent locus of the pitch peak in the tonal alignment across different syllable structures may serve as a robust perceptual cue for recognizing words in different types of the tonal classes in a tonal language like NKK. This remains for future research.

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Appendix

1. Phonetic transcription of experiment materials (phonemic transcription provided when necessary)

(1) The CVNCV structure

Nasals	LH	HL	HH
[m]	kamca 'potato'	namca 'man'	kə:mto 'fencing'
[n]	mantu 'dumpling'	panci 'ring'	pa:ntɛ 'opposition'
[ŋ]	koŋpu 'study'	noŋpu 'farmer'	na:ŋpi 'waste'

(2) The CVNV structure

Nasals	LH	HL	HH
[m]	namu 'tree'	komo 'aunt'	no:mo 'aged mother'
[n]	munə 'octopus'	nuna 'sister'	ta:nə 'word'
[ŋ]	paŋa 'mill'	toŋu 'man's name'	pu:ŋə 'carp'

(3) The CVNNV structure

Nasals	LH	HL	HH
[nn]	cənnam 'name of province'	ənni 'sister'	a:nnɛ 'guide'
[mm]	nommun /nonmun/ 'article'	simmun 'interrogation'	sa:mmun /sa:nmun/ 'prose'
[mn]	samnyən /samnyən/ 'three years'	simni /simli/ 'psychology'	simni /sipli/ 'ten miles'
[ŋm]	caŋma 'rainy season'	toŋmu 'friend'	ca:ŋmo 'wife's mother'
[ŋn]	koŋno /koŋlo/ 'merit'	saŋnom 'low man'	ca:ŋno /caŋlo/ 'elder'

2. Experiment materials written in Korean

(1) The CVNCV structure

a. LH class

감자, 만두, 공부

b. HL class

남자, 반지, 농부

c. HH class

검도, 반대, 낭비

(2) The CVNV structure

a. LH class

나무, 문어, 방아

b. HL class

고모, 누나, 동우

c. HH class

노모, 단어, 붕어

(3) The CVNNV structure

a. LH class

삼년, 논문, 전남, 장마, 공로

b. HL class

심리, 심문, 언니, 동무, 상놈

c. HH class

십리, 산문, 안내, 장모, 장로