Interface between Phonological Timing and Phonetic Duration in Korean*

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This paper has two main goals. One is to reexamine the representation of the underlying phonation contrasts in Korean consonants. The other is to show that there is a systematic relationship between abstract phonological notions such as timing and featural structures, and more concrete, quantifiable phonetic events such as closure duration. Instead of assuming a standard three-way underlying phonation contrast (plain, tense and aspirated), I propose that Korean tense consonants are underlyingly geminated plain segments and that the feature [constricted glottis] is redundantly specified. Geminate analyses of tense consonants have been generally rejected on the grounds that Korean has a syllable structure constraint prohibiting multiple consonants in the onset position. However, I argue that word-initial tense consonants lose one timing slot due to Stray Erasure, while intervocalic tense consonants keep both timing slots during the derivation. The application of Stray Erasure is supported by the results of acoustic and perceptual experiments. The phonological arguments and the results of phonetic experiments presented in this paper demonstrate that quantity and tension in the phonological structure are systematically reflected in their acoustic measurements and the listeners' perception.

1. Introduction

Korean is widely assumed to have a three-way underlying phonation contrast for stops and a two-way distinction for fricatives in initial position (Kim-Renaud 1974, Ahn 1985, Sohn 1987, Cho 1990). I call this as 'standard view' hereafter, which is clearly represented in the following

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consonantal phoneme inventory.

(1) Korean Consonantal Phoneme Inventory (based on Cho 1990)

	labial	alveolar	palatal	velar	glottal
plain stops	p	t	c	k	
aspirated stops	p^h	t^h	c^h	k^h	
tense stops	p'	t'	c'	k'	
plain continuants		s			h
tense continuants		s'			
nasals	m	n		ŋ	
	mm	nn			
liquids		l			
		ll			

In (1), sonorants show a geminate/singleton contrast, while obstruents are described as showing a three-way contrast. I do not discuss detailed explanations of the phonetic characteristics of three phonation types of stops, but briefly, plain consonants are produced with slight aspiration; aspirated consonants are strongly aspirated; and tense consonants are unaspirated and have some kind of tension involved in their articulation. All three types are voiceless; but in intervocalic position, plain consonants are frequently voiced. Under the standard view, tense and plain consonants are distinguished by the presence and absence of the feature specification of [+tense] or [+constricted glottis].

Instead of a three-way phonation type, some researchers (Martin 1954, 1982; Yu 1989; Kim 1990) argue that Korean tense (and aspirated) consonants are not singletons. In Kim (1990), tense and plain consonants are distinguished by the number of timing units associated with them on the timing tier: plain consonants occupy one timing unit, while tense consonants occupy two units. Thus tense consonants are plain geminate consonants.

In this paper, I develop the geminate point of view, arguing that Korean tense consonants are plain geminates underlyingly. However, my analysis explains more explicitly the relationship between the timing and featural structures of the tense consonants. Furthermore, I solve the outstanding problems with the previous geminate analyses with respect to the canonical syllable structure.

In providing an analysis of Korean consonants, I pursue a more comprehensive approach, encompassing phonology and phonetics in both acoustics and perception. This strategy is based on recent tendencies in generative phonology which reveal that real insight in phonology may be gained through a phonetic perspective and experimental phonetic studies can often provide useful input to an abstract phonological analysis (Pierrehumbert 1990; Keating 1984, 1990; Cohn 1990, 1993).

The organization of this paper is as follows. In § 2, I present a geminate analysis of Korean tense consonants, based on phonological and typological evidence. In § 3, I discuss the conflicts between a syllable structure constraint in Korean and the geminate analysis I propose. However, I show that this can be solved with the general principle of syllabification, namely, Stray Erasure. In § 4 and § 5, I show that my phonological argument presented in the previous section is supported by the results of acoustic and perceptual experiments respectively. In § 6, I conclude this paper by proposing an analysis to explain how phonological timing structures in Korean tense and plain consonants are mapped to their phonetic duration.

2. A Geminate Analysis of Korean Tense Consonants

2. 1. Geminate Reinforcement

According to the standard view, tense and plain consonants are underlyingly distinguished by the presence or absence of the tension feature, either [+tense] or [+constricted glottis].

I argue, however, that in the underlying representation, the surface tense and plain consonants are distinguished by the number of timing units associated with them on the timing tier: tense consonants occupy two units, while plain consonants occupy only one timing unit, similar to Kim (1990)'s analysis of tense consonants. In other words, the surface tense consonants are underlyingly plain geminates. Unlike the previous geminate analyses, however, I am explicit in deriving the surface representations from underlying forms. Under my analysis, geminate consonants, underlying or derived, get the feature of tension later in the phonology through a rule of Geminate Reinforcement (GR) as in

(2).

(2) Geminate Reinforcement[1] : C C
\ /
[αF] → [constricted glottis]

Due to GR, underlying or derived geminate obstruents are realized as the corresponding tense ones. Unlike the standard view, the feature [constricted glottis] is represented as a privative feature, following the notion that the laryngeal features are not binary but privative as proposed by Lombardi (1990) and others. The addition of the feature [constricted glottis] accounts for the fact that in surface representations, tense stops exhibit acoustic and articulatory characteristics distinct from their plain counterparts. In other words, there is more to the plain-tense distinction than simply timing. Even though tense and plain consonants are distinguished in terms of timing relations, on the surface they are also distinguished by featural specifications. None of the earlier geminate analyses explain how we get the property of tension on the surface.

The analysis proposed here suggests that the following three types of phonation contrasts are possible in surface representation in terms of the featural and structural specifications for obstruents.

(3) a. C b. C c. C C
| \ /
[CG] [CG]

I argue that all three types in (3) occur in the surface representations in Korean. (3a) is the representation of a word-initial tense consonant; (3b) is that of a word-initial or intervocalic plain consonant; and (3c) is that of a geminate tense consonant in intervocalic position.

2.2. Evidence for the Geminate Analysis of Tense Consonants

In this section, I present three sources of evidence in support of the

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[1] The Geminate Reinforcement rule in (2) has to be revised to account for the derived tense consonants(*muk* + *ta* → *mukt'a* 'tie') as well as the underlying tense ones. See Han (1996) for complete explanation.

claim that surface tense consonants are underlyingly plain geminates: surface realization of two plain obstruents, noun sub-compounding process, and language typology of geminates.

The first evidence has already been provided by the previous geminate analyses such as Yu (1989) and Kim (1990). I further provide a triplet to show that the segments [kk] and [k'] are indistinguishable on the surface. As discussed by Yu (1989) and Kim (1990), tense consonants are often the result of juxtaposing two homorganic plain segments across a boundary in allegro speech. Some examples presented in these two analyses are shown in (4).

(4)	mok + kwa	→ [mok'wa]	'neck, too'
	cip + pota	→ [cip'ota]	'house-sit' (Kim 1990: 147)
	mac + cəl	→ [mac'əl]	'mutual bowing'
	mus + salam	→ [mus'alam]	'people'
	tat + ta	→ [tat'a]	'to close'(Yu 1989: 31)

In each example of (4), two homorganic plain consonants are put together after a morphological process and then represented as a corresponding tense consonant. Under my proposal, the two homorganic plain obstruents trigger GR as in (2), since they are plain geminate obstruents. They are then represented as long tense consonants.

It is particularly interesting to compare cases in which surface tense segments are derived from different underlying sources. Let us consider the following three cases :

(5) a. ike pek kacita 'This is a hundred'
b. ike pek k'acita 'This is up to hundred'
c. ike pe k'acita 'This is to the boat'

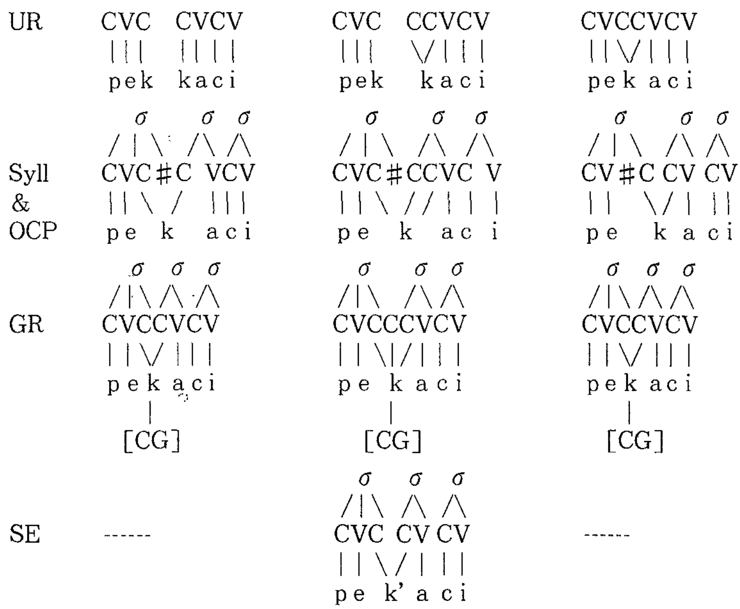
In (5a) two homorganic plain consonants juxtapose across a word boundary; in (5b) a plain consonant is followed by a homorganic tense consonant; in (5c) only one tense consonant appears at the onset. All three examples such as /k#k/, /k#k'/ and /#k'/ in (5) are pronounced identically. Impressionistically native speakers cannot distinguish these three utterances (Park et al. 1982). Under the standard view, at the surface level of representation, the consonant clusters in the first two cases are represented as [pekk'aci], since the first /k/

triggers the tensification of the following word-initial obstruent /k/, and tensification vacuously applies for the case that the initial segment of the following word is a tense segment, namely, /k'/. In the last case, however, only single tense consonant appears intervocalically. This analysis is illustrated as follows.

(6) /pek kaci/ > [pekk'aci] 'a hundred'
/pek k'aci/ > [pekk'aci] 'up to hundred'
/pe k'aci/ > [pek'aci] 'to the boat'

The standard view predicts distinct surface representations for the cases including clusters /k#k/ and /k#k'/ on the one hand and that including /#k'/ on the other. It cannot directly account for the fact that native speakers cannot distinguish these three types. In my analysis, on the other hand, all three types are represented as tense geminates on the surface as shown in (7).

(7) a. /pek#kaci/ 'a hundred' b. /pek#kkaci/ 'up to hundred' c. /pe#kkaci/ 'to the boat'



SR [pekk'aci] [pekk'aci] [pekk'aci]

(SE = Stray Erasure)

(7a) is the case where both timing slots for /k/ are syllabified. In (7b), only one member of the word-initial geminate is syllabified for an onset of the second syllable, and then the other member of a geminate is deleted after the GR applies, as a result of Stray Erasure (Steriade 1982):

(8) Stray Erasure Convention
Erase segments and skeleton slots unless attached to higher levels of structure. (Steriade 1982: 82)

I assume that the Stray Erasure Convention applies to the unsyllabified segments at the end of derivation. In (7c) we see that one member of a geminate is syllabified as a coda of the preceding syllable, while the other member is syllabified as an onset of the second syllable. On the surface this geminate is represented as a long tense consonant.

Thus the surface realization of two plain obstruents provides evidence to support the view that tense consonants are plain geminates. The equation of /k+k/, /k+k'/ and /k'/ is also supported by EMG data by Park et al. (1982).

The EMG data of the Korean velar stops by Park et al. (1982) give us articulatory evidence for the equation of /k + k/, /k + k'/ and /k'/. Park et al. (1982) investigated electromyographically the laryngeal adjustments for Korean velar stops in syllable-initial and syllable-final positions. The averaged EMG curves of the thyroarytenoid (VOC) for three phonation type stops in the syllable initial position are illustrated in Fig. 1.

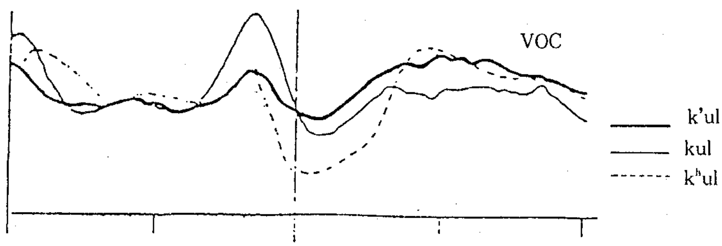


Fig. 1. Averaged EMG curves of the thyroarytenoid (VOC) for the utterance type *ike Culita*, where C stands for the tense (thick line), the plain (thin line) and the aspirated (dashed line). The line-up for averaging was taken at the implosion of each stop consonant. (following Park et al. 1982)

At the implosion of the stop closure, VOC activity is suppressed for the production of the three phonation type stops. The degree of VOC suppression is slightest for the tense type and most marked for the aspirated type, while it is moderate for the plain type.

On the other hand, the EMG curves of VOC for the three sentence types *ike pek kacita* 'This is a hundred', *ike pek k'acita* 'This is up to hundred', and *ike pe k'acita* 'This is to the boat' show that the degree and the timing of VOC suppression for consonant segments /k#k/, /k#k'/ and /#k'/ are extremely similar to each other, as seen in Fig. 2.

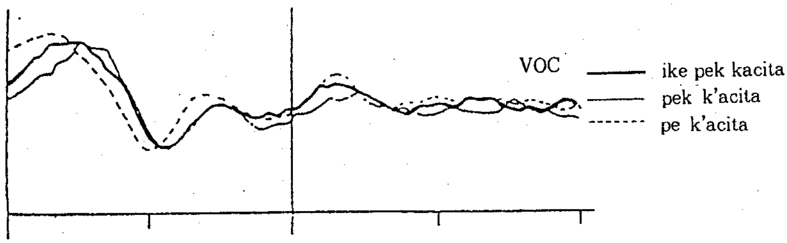


Fig. 2. Averaged EMG curves of VOC for the utterances *ike pek kacita* (thick line), *ike pek k'acita* (thin line) and *ike pe k'acita* (dashed line)(following Park et al. 1982).

Thus the results of this study indicate that patterns of VOC activity for the consonant clusters across the word boundary consisting of a syllable-final consonant and a syllable-initial tense and plain consonants are quite similar to those of the syllable-initial tense consonant.

The similarity of the EMG curves in these three types including not only degree of muscle activity but also duration does not follow the standard view and additional rules would be required to account for the above pattern. In geminate analyses, on the other hand, all three types are underlyingly plain geminates and are then represented as tense geminates at the surface level of representation. Therefore the three curves in Figure 2 support the claim that tense consonants are plain geminates.

The second evidence comes from the analysis of noun sub-compounding process, which is also known as "Sai-sios" or "Bindung-s Rule" in the literature, as has been dealt with by a number of researchers of different theoretical orientations (Kim-Renaud 1974, Ahn 1985, Sohn 1987, Cook 1987, Kim 1990, and others). In this paper, I present Sohn (1987)'s analysis among them, and I argue that if we follow a geminate analysis of tense consonants, we can avoid the complication introduced by her analysis. In what follows, I present first my analysis based on some theoretical assumptions and then compare it with Sohn's analysis.

Let us first consider the representative alternation patterns in the sub-compounding. Sohn (1987) presents the following examples.

(9) a. [+son] + [-son] → [+son] $\begin{bmatrix}\text{-son}\\ \text{CG}\end{bmatrix}$

cam 'sleep' + cali 'place'	→ [camc'ali]	'sleeping place'
san 'mountain' + kil 'path'	→ [saŋk'il]	'mountain path'
tuŋ 'lamp' + pul 'light'	→ [tuŋp'ul]	'lamp light'
sol 'pine' + paŋul 'small bell'	→ [solp'aŋul]	'pine cone'

Vowel + [-son] → V $\begin{bmatrix}\text{-son}\\ \text{CG}\end{bmatrix}$

næ 'river' + ka 'side'	→ [næk':a]	'riverside'
cho 'candle' + pul 'light'	→ [chop':ul]	'candle light'
toŋci 'winter solstice' + tal 'moon'	→ [toŋjit':al]	'December'

b. V + V -> V /t/ V

u 'upper part' + əlɨn 'elders'	→ [udəlɨn]	'seniors'
u 'upper part' + os 'clothes'	→ [udot]	'upper clothes'

c. V + [+nas] → V [+nas][+nas]

i 'teeth' + mom 'body'	→ [immom]	'gum'
næ 'river' + mul 'water'	→ [næmmul]	'stream water'
alæ 'lower part' + ni 'teeth'	→ [alænni]	'lower teeth'
k^ho 'nose' + nal 'line'	→ [k^honnal]	'nose line'

A genitive marker is inserted between the two elements of a compound, and appears with various surface forms as in (9). In a case where the right element of a compound begins with an obstruent, it is tensed as in (9a). In (9b) the genitive marker is inserted between two vowels across the boundary, the segment /t/ is inserted between two elements of a compound. When the left element of a compound ends with a vowel, but the right element begins with a nasal, the nasal is geminated in (9c). Overall the typical phonological effects of the sub-compounding are tensification, /t/ epenthesis and nasal epenthesis.

Sohn (1987) argues that the epenthetic genitive marker is an empty skeletal slot. Her analysis is based on Underspecification Theory (Archangeli 1984) such that /t/, the least marked consonant in Korean, is underspecified as an empty skeletal slot. If I reinterprete the empty skeletal slot as an empty C-slot in the framework of CV phonology, the empty C-slot is filled in with the features of [t] by predictable specification missing in the underlying representation. This is done in terms of default rules at a later stage of the derivation. Based on this assumption, Genitive Marker Insertion can be formalized as in (10).

(10) Genitive Marker Insertion (GMI)

$\emptyset \rightarrow C$ /] ___ [

(An empty C-slot is inserted between two elements of a compound.)

Based on these assumptions, I argue that all the examples in (10) are derived as in (11).

```
(11)        a. /næ + ka/      b. /u + əlin/     c. /alæ + ni/

UR           CV CV             V VCV C           VCV CV
             | | | |           | | | | |         | | |  | |
             n æ k a           u  ə l ɨ n        a l æ  n i

              σ   σ            σ σ   σ           σ  σ   σ
GMI          /|\ / \           | /\ /|\          | /|\ /\
& Syll       CVCC V            VCVCVC            VCVCCV
             | |  | |          |  | | | |        | | |  | |
             n æ  k a          u  ə l ɨ n        a l æ  n i

              σ   σ                              σ  σ   σ
C-linking    /|\ / \                             | /|\ / \
             CVCC V            ------            VCVCC V
             | | \| |                            | | | \| |
             n æ k  a                            a l æ n  i

              σ   σ
GR           /|\ /\
             CVCCV             ------            ------
             | | \/ |
             n æ k a
                 |
               [CG]
```

```
                                σ σ   σ
default      ------             | /\ /|\          ------
                                VC VCVC
                                || ||||
                                u t ə l ɨ n
SR           [næk'ːa]           [udəlɨn]          [alæni]
```

After an empty C-slot is inserted between the two elements of a compound, it is syllabified as are other segments. In (11a) and (11c) an empty C-slot is linked to any adjacent consonantal segment (C-linking). In (11a), this triggers an application of GR, but in (11c) GR does not occur, since the segment with the feature [CG, +nasal] does not meet the environment for GR as we saw previously. In (11b), the empty C-slot is filled with the missing features by default rules at a later stage of derivation.

Sohn (1987: 241-263) provides a somewhat different idea from the one proposed here. According to Sohn, the epenthetic genitive marker is an x-slot linked to the feature [+CG], which triggers tensification or comes out as /t/ or nasals according to the context. One problem with this analysis is that the epenthetic x-slot needs to be erased later in the case of triggering tensification as in (9a), since no two consonants are allowable in the onset as well as coda position. This is more clearly illustrated with the sample derivation of /cam + cali/ to [camc'ali] 'sleeping place'.

(12) /cam + cali/ → [camc'ali]

```
      σ                σ  σ
     /|\         ~~   /\ /\
     x x x      (x)   x x x x
     | | |       |  ⁄ | | | |
     c a m   [+CG] c  a l i
```

In (12), the empty x-slot linked to the feature [+constricted glottis] is deleted after this feature is spread to the following obstruent. This results from the fact that Sohn does not analyze tense consonants as geminates. But the analysis proposed here, namely a geminate analysis of tense consonants, does not have such a stipulation. Similarly, the feature [+CG] should be also deleted after it is spread, since it does not surface. Thus on the surface, Sohn has to delete either X slot or the feature [+CG] in each case. It is clearly the case that Sohn's analysis is too much complicated on the surface. My analysis, however, captures the tensification case directly.

Third, the language typological observation serves as evidence for a geminate analysis of tense consonants. There is a strong cross-linguistic tendency for languages with geminates to show the contrast within both obstruents and sonorants, rather than only one or the other of them in the underlying phoneme inventory.

A language survey from several sources including the examination of the phonemic inventories present in the UCLA Phonological Segment Inventory Database (UPSID) (Maddieson 1984) identified 30 languages have long consonants, which we consider as geminates. Of the 30 languages which have geminate consonants, 22 languages have both sonorant and obstruent geminates. These languages consist of 12 languages from the UPSID such as Punjabi, Finnish, Yakut, Wolof, Arabic, Shilha, Somali, Maranungku, Delaware, Wichita, Japanese, and Chuvash. The 10 languages from other sources are Italian (Smith 1992), Pali (Geiger 1968, Murray 1982, Zec 1994), Seyalarise (Mithun and Basri 1986), Luganda (Clements 1986), Sinhala (Fairbanks, Gair and De Silva 1968), Ponapean (Rehg and Sohl 1981), Hausa (Cowan and Schuh 1976), Madurese (Cohn and Lockwood 1994), Malayalam (Mohanan 1968) and Fula (Arnott 1970). Three languages out of the database have only sonorant geminates: these are Piro (Matteson 1965), Ocaina and !Xu. In five languages, quantity is contrastive only in obstruents. Greenlandic, Lak, Iraqw and Ngzim (Schuh 1972) and Kaliai (Counts 1969) are such languages. On the basis of the language typology presented so far, although not a systematic study, it would appear that distinctive quantity is quite commonly found in both sonorants and obstruents.

A very similar pattern is found in Taylor (1985)'s typological survey, based on the Stanford Phonology Archive (Crothers et al., 1979). This study shows that of the 197 langauges in SPA, 28 languages have long consonants (Somali, Awiya, Tigre, Amharic, Maltese, Wolof, Songhai, Kanuri, Mahas, Punjabi, Hindi, Sinhalese, Finnish, Yakut, Japanese, Lak, Kurukh, Telugu, Chamorro, Maranungku, Inuit, Ojibwa, Wichita, Nez Perce, Totonac, Island Carib, Goajiro, Ocaina). This survey shows that all these 28 languages have at least one geminate obstruent, even though four of them do not have sonorant geminates. Thus most languages have both sonorant and obstruent geminates and if there is only one type, it might be obstruent rather than sonorant geminates. Based on these data, she hypothesizes that "if a language has at least one geminate sonorant, it will also have at least one geminate obstruent" (p. 122). The results of this survey are in good agreement with those of my survey; the distinctive quantity is found in both sonorants and obstruents.

Turning to the Korean case, we have already seen in the phoneme inventory in (1) that Korean has sonorant geminates such as /mm, nn, ll/ (/əmma/ 'mother', /ənni/ 'sister'). Some examples with geminates are shown in (13), together with the words with corresponding non-geminates.

(13) a.	kammyən	'reduction and exemption'
	kamyən	'mask'
b.	məlli	'far (away)'
	məli	'head'
c.	kannan	'hardships, difficulties'
	kanan	'poverty'

Each minimal pair in (13) clearly shows that nasals /m, n/ and a liquid /l/ show distinctive quantity contrast in Korean.

Following the standard view that tense consonants are singletons, Korean would have an odd system, since geminate contrasts are only found in sonorants. Under the analysis proposed here, however, a much less marked system is observed. Geminates are found throughout the inventory in both sonorants and obstruents.

Related to this typological issue, I show that the geminate analysis of tense consonants further has an effect of bringing a less marked system to Korean in another respect. Under a geminate analysis of tense consonants, Korean has a very common two-way phonation contrast between plain voiceless vs. aspirated in the obstruents. This type of two-way system is well represented in terms of language typology. According to UPSID, 162 languages have two-way phonation contrast.

They have typically plain voiceless/voiced contrast (117 languages). A further 27 have a contrast along the voice onset time continuum, voiced vs. aspirated or voiceless vs. aspirated. Thus the contrast voiceless vs. aspirated is more common than the three-way phonation system, plain, tense and aspirated, as the standard view assumes. Moreover, Korean tense consonants are not the typical type of glottalized consonants such as ejectives or implosives.

Overall the geminate analysis of tense consonants in Korean leads to a less marked phonation system in two respects. First, Korean has both sonorant and obstruent geminates. Second, Korean shows a two-way phonation contrast, which is well represented in the world languages.

3. A Syllable Structure Constraint and Stray Erasure

In this section, I show that the strong syllable structure constraint in Korean, which allows only single consonants in the onset as well as the coda, explains the syllabification pattern of geminates in both intervocalic and word-initial positions.

As is widely accepted, the maximal syllable structure of Korean at surface representation is (C)(G)V(C); Korean syllable can contain an onset and a coda, but each of these includes no more than one consonant. The strength of the canonical syllable structure is nicely illustrated by the syllabification of underlying clusters in coda position. When they are followed by a vowel, one of the consonants in the coda is syllabified as an onset of the following syllable as in (14a). On the other hand, when they are followed by a consonant or a word boundary, one of these consonants is deleted as in (14b) and (14c) respectively.

(14) a. /kaps/ 'price'+ /i/ 'subject marker' → [kap si] 'Price is …'
b. /kaps/ 'price'+/to/ 'too' → [kap to] 'Price, too'
c. /kaps/# → [kap] 'price'

Allowing geminates in onset position as in /ttal/ 'daughter', or in the post-consonantal position as in /suyaŋttal/ 'foster daughter' would have some conflicts with the syllable structure constraint; these segments cannot be resyllabified. As for this possible problem, previous geminate analyses such as Martin (1954, 1982), Yu (1989), or Kim (1990) add a statement to the grammar such that geminate consonants are exclusively permitted as an onset of the syllable.

I argue, however, that this is a needless complication when we hypothesize that one C-slot of a geminate in initial position is lost by Stray Erasure after the GR applies. More specifically, I argue that geminates in intervocalic position keep their own timing slots throughout the derivation, while those in initial or post-consonantal position lose one C-slot due to Stray Erasure, since only one C-slot can be incorporated into the syllable structure. We can see this more clearly through example derivations of the consonants in intervocalic and initial /post-consonantal positions. First let us consider the case of intervocalic tense consonants as in (15).

```
(15)                      /tok+ki/        /tokki/
                          'spite'         'axe'

                           σ   σ           σ  σ
                          /|\  /\         /|\ /\
Syllabification           CVC  CV         CVCCV
                          |||  ||         || \/|
                          tok  ki         to k i

                           σ   σ
                          /|\  /\
Word Formation            CVC+CV           ------
                          |||  ||
                          tok  ki

                           σ  σ
                          /|\ /\
Geminate Formation        CVCCV            ------
(by OCP)                  || \/|
                          to k i

                           σ  σ            σ  σ
                          /|\ /\          /|\ /\
GR                        CVCCV           CVCCV
                          || \/|          || \/|
                          to k i          to k i
                             |               |
                           [CG]            [CG]

SR                        [tok':i]        [tok':i]
```

The two examples in (15) are distinguished from each other in their underlying representations in that the tense /k/ in 'axe' is an underlying geminate, while the two /k/'s in 'malice' are included in separate morphemes, one in the coda of /tok/ 'poison' and the other, the onset of /ki/ 'vapor'. These two /k/'s are, however, brought together during word formation to create the word 'malice', and then represented as a geminate due to the Obligatory Contour Principle (McCarthy 1986). As a result, both examples trigger the application of GR, and appear as long tense stops on the surface.[2]

Let us now turn to the syllabification of geminates in the word-initial or post-consonantal position.

```
(16)                  /sonttæ/               /ttam/
                 'dirt from hands'       'perspiration'

                      σ     σ                 σ
                    / | \   / \             / | \
Syllabification     C V CC C V              CC V C
                    | | |\/ |               \/ | |
                    s o n t  æ               t  a m
```

[2] As pointed out by one of the reviewers, standard analyses assume that tensification occurs in two different kinds of context with respect to speech rate, namely, in allegro speed vs. in slow or emphatic speed. Kim-Renaud (1987: 351), for example, proposes the following surface representations for /tat + ta/.

tat + ta → tatt'a or tat'a 'to close'

According to Kim-Renaud, form with a geminate [tatt'a] is basic, and form without a geminate [tat'a] is optionally derived in allegro speech. However, a recent acoustic study by Johnson and Oh (1995) show that first, intervocalic tense consonants in Korean are phonologically geminates; second, in intervocalic position, only the forms with geminates appear regardless of a speech rate, but intervocalic tense consonants are more compressible in faster speech than are post-consonantal tense consonants. Based on these results, Johnson and Oh conclude that forms without geminates such as [tat'a] result from a phonetic realization, not a categorical rule as argued by Kim-Renaud. Based on such evidence, two surface forms in the phonology as Kim-Renaud proposes do not appear to be permitted.

```
                  σ    σ                σ
                 / | \  /\             / | \
GR               C V CCC V             CC V C
                 |  |  |\/ |            \/ |  |
                 s  o n t  æ            t  a m
                         |              |
                       [CG]           [CG]

                  σ    σ                σ
                 / | \ /\              / | \
Stray Erasure    C V CC V              C V C
                 |  |  || |            |  |  |
                 s  o n t æ            t  a m

SR               [sont'æ]              [t'am]
```

In (16), syllabification applies first, and only one C-slot of the onset in /ttæ/ and /ttam/ is syllabified. After the underlying geminates are tensed by GR, one C-slot of each example is deleted, since only one C-slot can be syllabified in the onset position. Consequently, each example appears as a short tense /t/ in the surface representation. The sample derivations provided in (15) and (16) show that the tense consonants in initial as well as medial positions do not conflict with the syllable structure constraint of Korean after application of Stray Erasure.

The analysis proposed here predicts that intervocalic tense consonants will be longer than word-initial or post-consonantl tense segments. This is abundantly supported by the acoustic and perceptual evidence.

4. Acoustic Evidence for Stray Erasure in Word-Initial Tense Consonants

In this section, I present the results of acoustic experiments to measure the closure duration of tense and plain stops in two prosodic positions, word-initial and intervocalic, as phonetic evidence for the application of Stray Erasure in word-initial tense consonants. Given my phonological argument that word-initial geminates lose one timing slot due to Stray Erasure, we predict that the closure duration of intervocalic tense consonants is significantly longer than the corresponding plain ones in word-initial position. To test this, I measured the closure duration of bilabial and alveolar stops with respect to prosodic position (word-intial vs. intervocalic) and phonation type (tense vs. plain). The test words and the frame sentences are presented in (17) and (18).

(17) Test Words

position		phonation			
		tense		plain	
V_V	alveolar	at'a	'*'	ata	'*'
	bilabial	ap'a	'father'	apa	'*'
#_	alveolar	t'a	'to pick'	ta	'to touch'
	bilabial	p'a	'to mash'	pa	'to see'

'*' = nonsense words

(18) Frame Sentences

#_ : sakwa ____cuseyo 'Please ____ the apple'

V_V : ikən ____ eyo 'This is ____'

The results from two male native speakers are presented in Table 1.

Table 1. Closure Duration (ms) of Bilabial and Alveolar Stops in Korean

	intervocalic		word-initial		totals
	labial	alveolar	labial	alveolar	
tense	142(12)	137(11)	83(11)	78(11)	110(45)
mean	140(23)		80(22)		
plain	15(12)	54(12)	55(11)	53(12)	55(47)
mean	56(24)		54(23)		
totals	100(24)	94(23)	69(22)	65(23)	89(92)

( ) : number of tokens

In Table 1, the difference in length is clear between in the intervocalic and word-initial tense consonants on the one hand and that between intervocalic tense and plain consonants on the other hand. First, the duration of tense consonants in intervocalic position is significantly longer than that in initial position: intervocalic tense consonants are more than twice as long as those in initial position. I argue that this directly reflects the difference in the timing tier, namely, two timing units for intervocalic tense consonants, and one timing unit for word-initial ones. The raw figures of duration are well matched to the proposed timing structure. Second, the durations of tense and plain consonants in initial position are also significantly different (p=.0001), but the difference is not as great as in the above case. I hypothesize that this difference is not from the timing distinctions. This is attributed to the fact that tense segments, namely segments with the feature [CG] are usually longer than plain ones, in spite of having the same number of timing units. The feature [CG] at the segmental tier only contributes to a small amount of duration. The highly significant longer duration of tense consonants as compared to plain consonants in intervocalic position, which is almost three times as long, can be accounted for as the phonetic realization of duration differences at both tiers, skeletal tier and segmental tier. The intervocalic tense consonants are significantly longer than word-initial plain consonants, because the former has two timing units in the skeletal tier, while the latter has only one. In addition to the duration facts from the timing relations, intervocalic tense consonants are longer because they acquire the feature [CG] at the segmental tier. Word-initial plain consonants do not undergo lengthening due to such structural or featural properties. Finally, there is no significant difference for the plain consonants in each position, intervocalic vs. word-initial. This can be easily explained by the fact that there is no change in the timing relations as well as the featural relations between the plain consonants in each prosodic position.

The results of the experiment support the claim that intervocalic tense consonants are geminate segments occupying two positions on the timing tier, while at word-initial position underlyingly geminates are simplified to single segments. Similar results on the duration difference between initial and intervocalic tense stops are found in Silva (1992) and Johnson and Oh (1994).

Overall the results of the acoustic measurements are in good agreement with my phonological claims about timing and featural relations between the tense and plain consonants. These duration facts cannot be accounted for under the standard view where tense consonants are expressed with the feautre [CG] or [+tense] specification regardless of the prosodic position they occur.

5. Perceptual Evidence for Stray Erasure

In this section, I provide further evidence for the application of Stray Erasure in word-initial tense consonants, by representing the results of perceptual experiments. In the acoustic experiment presented in the previous section, the closure duration of tense stops in intervocalic position is significantly longer than that in initial position, while the duration of tense and plain stops in initial position is also significantly different, but the difference is much smaller than in the case of intervocalic position. Based on these results, we expect that when the manipulated closure duration of tense and plain stops in intervocalic position are presented to listeners, they will perceive stimuli with longer closure duration as tense consonant-like, and those with relatively shorter duration as plain consonant-like. We also predict that the manipulation of closure duration might not contribute to the perception of consonants in word-initial position.

The method used in constructing stimuli is similar to that used by Hankamer, Lahiri and Koreman (1989). The original closure durations of the test tokens used for creating stimuli were 43 ms for plain stops and 127 ms for tense stops, both of which were quite close to the average value of closure duration of these phonation types. As for the initial position, the durations of the test tokens were 51 ms for plain stops, and 74 ms for tense ones. To create the test stimuli, I took equal intervals of 10 ms between minimum closure duration of plain stops and the maximum closure duration of tense stops. The silent interval corresponding to the closure of original tense and original plain stops was replaced, using a waveform editor, by silence intervals of 35, 45, 55, 65, 75, 85, 95, 105, 115, 125, 135 ms in intervocalic position, and 55, 65, 75, 85, 95, 105 ms in initial position.

The results of the perception experiments from twenty subjects are presented in Fig. 3 and Fig. 4.

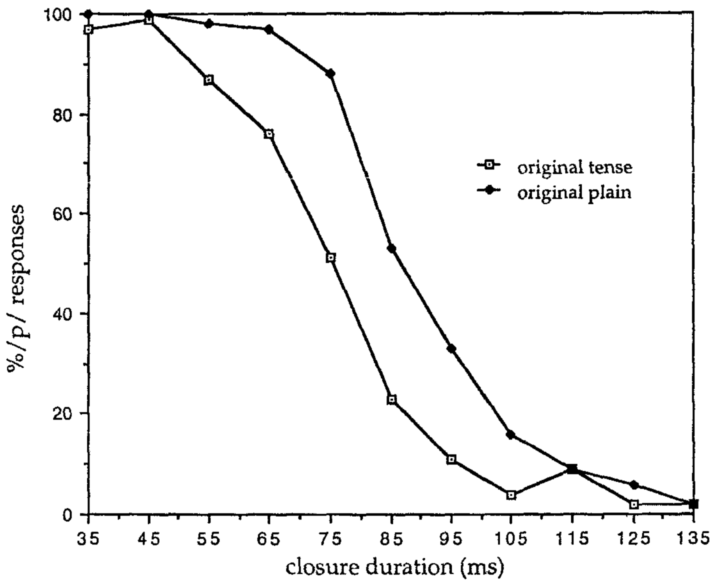


Fig. 3. Mean Percentage /p/ Responses at Different Closure Durations for Continua Created From Intervocalic Tense and Plain Stops.

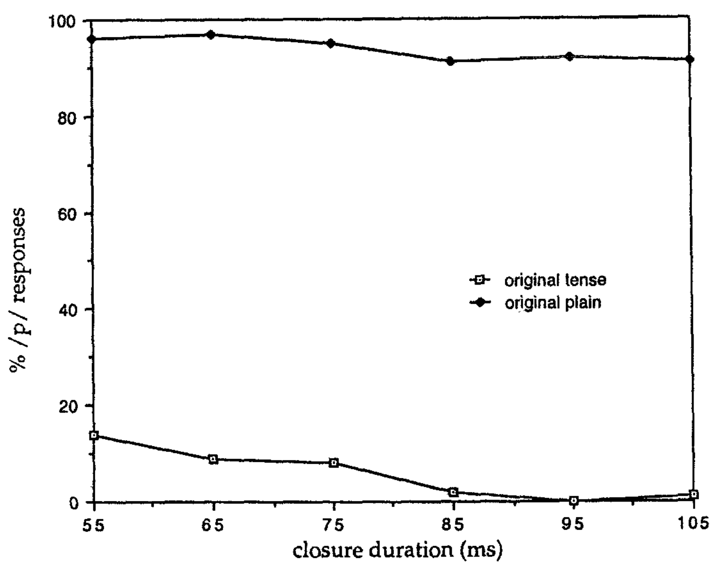


Fig. 4. Mean Percentage /p/ Responses at Different Closure Durations for Continua Created From Initial Tense and Plain Stops.

Fig. 3 and Fig. 4 show the mean percentage plain consonant responses at different closure durations. The line connected with diamonds represents responses to stimuli created from an original plain consonant /p/; the line connected with squares represents responses to stimuli created from an original tense consonant /p'/. The curves in Figure 3 show that Korean native subjects perceived the stimuli categorically, with shorter closure durations giving rise to plain percepts and longer closures giving rise to tense percepts. Thus closure duration is shown to be a primary cue to distinguish tense from plain consonants in intervocalic position. These results are consistent with those of the acoustic experiments in previous section, where tense consonants are much longer than plain ones in this position. The durational difference between these two categories is perceptually salient so that subjects employ the closure duration as a cue to distinguisy tense and plain stops. These findings also fit well with the phonological analysis that intervocalic tense consonants are structually distinguished form intervocalic plain ones: the former occupy two timing units, while the latter occupy only one unit.

On the other hand, Fig. 4 shows that subjects did not perceive the stimuli categorically and that two curves, one from an original tense stop, and the other from an original plain stop, were very different. Regardless of the manipulated closure duration, stimuli made from an original tense stop were perceived as tense, while stimuli created from an original plain stop were perceived as plain. These results show that closure duration is not a factor to distinguish tense from plain consonants in word-initial position. These are in good agreement with the phonological argument that in word-initial position, both tense and plain consonants have only one timing slot, and thus structurally indistinguishable. Moreover, it is consistent with the observations I made based on the acoustic measurments: the length difference between initial tense and plain stops is much smaller than that between the two stop categories in intervocalic position. Even though the length difference between these two categories is statistically significant, the results of the perceptual experiments reveal that this small difference does not contribute to the differentiation of tense and plain stops.

Overall it was observed that closure duration is an important cue for differentiating tense and plain consonants in intervoclaic position, but not in word-initial position. These results, together with those from acoustic measurements, directly support the application of Stray Erasure of tense consonants in initial position.

6. Conclusion: Model for the Mapping of Phonological and Phonetic Timing

In this paper, I attempt to provide a comprehensive approach to the analysis of Korean tense and plain consonants, bridging three different kinds of representations: phonology, acoustics, and perception. The phonological timing relations I propose for Korean tense and plain consonants are systematically reflected in the observed acoustically and perceptually relevant differences in duration.

The results of the phonetic experiments in this paper confirm the claims by Pierrehumbert (1990), Keating (1984, 1990) and Cohn (1990, 1993) that there is a systematic relationship between phonological and phonetic representations. Based on such evidence, I explain further how the phonological timing is mapped to the phonetic duration more specifically, based on a model of grammar as shown in Fig. 5.

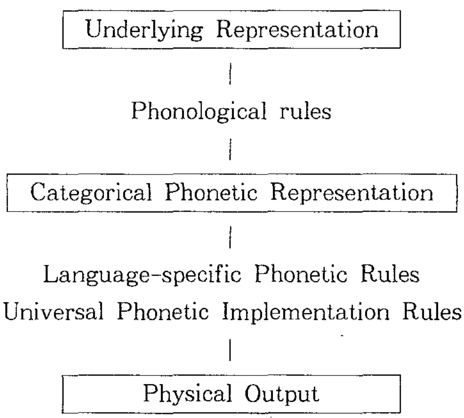


Fig. 5. The Phonological and Phonetic Representations Based on a Model of the Grammar.

Following Keating (1990), certain types of phonetic rules are assumed to be language-specific, not universal and thus need to be treated separately from the universal phonetic rules. However, the model in Fig. 5 is different from Keating's in two respects: first, the categorical phonetic representation is expressed as the output of the phonology in this model; and second, language specific and universal phonetic components are not treated with a separate step, with some ordering between them. Because there has been no specific evidence for the separation or ordering for these two components, here I would take a simpler model.

The timing contrasts in the underlying representation are very simple. Regardless of the inherent duration of segments, geminates and non-geminates are represented as assigned two and one units respectively:

(19) a. geminates (tense stops) b. singletons (plain stops)

```
        C  C                        C
         \ /
        [-son]
```

The next step is the application of phonological rules to the underlying geminates and singletons. First a Geminate Reinforcement rule applies whereby underlying or derived geminates get the feature [CG]. The result is as follows.

(20) a. geminates (tense) b. singletons (plain)

```
        C  C                        C
         \ /
        [CG]
```

The underlying or derived geminates show the form of (20a), while non-geminates have the same form as in the underlying representation as in (20b). Another relevant phonological rule is Stray Erasure. Word-initial geminates, although they have two timing slots in the underlying representation, lose one timing slot at the end of derivation, since it is not incorporated into the syllable structure. As a result, the following three forms occur at the output of the phonology.

(21) a. intervocalic geminates b. initial geminates c. singletons

a. intervocalic geminates	b. initial geminates	c. singletons
C C	C	C
\ /	|	
[CG]	[CG]	

(21a) represents the intervocalic geminates, keeping their timing slots during the derivation. The word-initial underlying geminates are shown in (21b), losing one of their C-slots. On the other hand, underlying non-geminates remain constant without any structural or featural change as in (21c).

The real duration and actual quantities are assigned to these outputs (22i), considering segment-inherent or language-specific duration properties. In Korean, geminates are about twice as long as the corresponding non-geminates. Thus as in (22ii), certain amount of duration corresponding to these timing contrasts is assigned to each segment after the segment-inherent duration is assigned. In (22iii), some amount of extra duration is then assigned to the segments specified with the feature [CG], which is not shown to be as great as that for the timing distinction. The feature [CG] contributes to small amount of duration in tense consonants as compared to the corresponding plain segments. This makes intervocalic and word-initial geminates a little bit longer. These durations are then adjusted for other factors, linguistic and extralinguistic, which can lengthen or shorten the duration of each segment. which is illustrated in (22iv).

(22)

	a. intervocalic tense	b. initial tense	c. plain
i. output of phonology	C C \ / [CG]	C | [CG]	C
ii. duration for the timing	| ____ | _ | closure release	| __ | _ | clo. rel.	| __ | _ | clo. rel.
iii. duration for the feature [CG]	| _____ | _ | clo. rel.	| ___ | _ | clo. rel.	------
iv. adjustment from other factors	| _____ | _ | → ← ← →	| ___ | _ | → ← ← →	| __ | _ | → ← ←→

Note that speaking rate, focus and other extra-phonological or extralinguistic factors are not directly accounted for. After the assignment of these durations, the result is the physical output in the model, which is represented as raw figures as were presented in section 4.

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