*UCLA Working Papers in Linguistics, vol. 1, October 1999*
*Papers in Phonology 2—Matthew K. Gordon (ed.)*

# INTRA-DIALECTAL VARIATION IN KOREAN CONSONANT CLUSTER SIMPLIFICATION: A STOCHASTIC APPROACH[*]

*[This paper was published in CLS 35, pp. 43-57]*

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In Korean, a tri-consonantal sequence in *VC1C2-C3V* is reduced to*VC1-C3V* or*VC2-C3V* depending on the type of consonant sequence or dialect. While previous OT work accounted for variations between dialects by reranking constraints, possible intra-dialectal variations have rarely been discussed. This paper provides an Optimality Theoretic account of free variation in tri-consonant cluster reduction. The first goal is to show, based on data collected from 8 Seoul speakers, that there is substantial intra-dialectal variation in consonant cluster reduction, which is far more complicated than has been previously discussed. Second, building on Jun's phonetically-driven OT account, this paper provides further evidence that phonetic factors plays a pivotal role in determining complex patterns of the consonant reduction. In doing so, relationship between tri-consonant reduction and place assimilation will be also discussed. Finally, this paper shows that the relative frequency of the variants can be correctly captured by the Gradual Learning Algorithm (Boersma & Hayes 1999) in which constraints are ranked stochastically on a continuous scale with possibly overlapping values.

## 1. INTRODUCTION

In Korean, tri-consonantal sequences are usually reduced to di-consonantal sequences, deleting either the first or the second member of the cluster. Which consonant deletes depends on the kind of segments which constitute the cluster, or the dialect of the speaker (e.g., Kim-Renaud 1974, Y-M. Cho 1990). Some examples in Seoul Korean are given in (1):

(1) Seoul Dialect (Based on Kim-Renaud (1974); '{}' refers to a deleted segment)

**• $C_1C_2C_3 \rightarrow C_1\{C_2\}C_3$**

| | | | | |
|---|---|---|---|---|
| a. | kaps+to | → | kap{s}to | 'price+and' |
| b. | moks+to | → | mok{s}to | 'share+and' |
| c. | anc+ta | → | an{c}ta | 'sit+DEC' |
| d. | hult$^h$+ta | → | hul{t$^h$}ta | 'browse+DEC' |

**• $C_1C_2C_3 \rightarrow \{C_1\}C_2C_3$**

| | | | | |
|---|---|---|---|---|
| e. | kolm+ta | → | ko{l}mta | 'to pester' |
| f. | kulm+ta | → | ku{l}mta | 'to fast' |

In the clusters in (1), $C_2$ is deleted, while in (2) $C_1$ is deleted. While the reduction processes in (1) are obligatory in Seoul Korean, there are other tri-consonantal sequences in which the consonant reduction applies optionally, resulting in free variation as shown in (2):

[*] I would like to thank Donca Steriade and Sun-Ah Jun for their valuable comments and encouragement. Further, I am very much grateful to my colleagues, Adam Albright and Christina Foreman for proofreading the final version of the paper along with helpful suggestions; and other members of the UCLA Phonetics Lab for comments on earlier presentations of the work. This paper is to appear in CLS 35.

(2) Free-Variation

| | | | |
|---|---|---|---|
| a. /lk+C/ | → | {l}kC ~ lkC | |
| e.g., ilk+**ta** | → | i{l}kta ~ ilkta | 'to read+DEC' |
| kilk+ta | → | ki{l}kta ~ kilkta | 'to scrach+DEC' |
| b. /lp+C/ | → | l{p}C ~ lpC | |
| e.g., palp+**ta** | → | pal{p}ta ~ palpta | 'to step+DEC' |
| yalp+ta | → | yal{p}ta ~ yalpta | 'to be thin+DEC' |

According to many researchers (e.g., Kim-Renaud 1974, Y. Cho 1990, Iverson & Lee 1994, J. Jun 1998 among many others), when the underlying consonant clusters consist of /l/ and /k/, it is /l/ that is deleted if the reduction applies optionally as in (2a). On the other hand, when the cluster contains /l/ and /p/, it is not the /l/, but rather the /p/ that is deleted, as in (2b).

This asymmetric consonant deletion phenomenon has been dealt with in a variety of phonological frameworks, from the early generative phonology (Kim-Renaud 1974), to non-linear phonology (Y. Cho 1990) and early Optimality Theory (Iverson & Lee 1994), and most recently in phonetically driven Optimality Theory (J. Jun, 1998). These previous analyses have captured a number of crucial intuitions about Korean cluster simplification, but they have also ignored some relevant aspects of the data. First, following Kim-Renaud (1974), many Korean phonologists have overlooked a third variant besides the two variants given in (2), namely [il{k}ta] and [pa{l}pta] in Seoul Korean. Second, they have only considered contexts where C3 is /t/ (presumably in order to simplify the data for expository purposes) but they have not tested the possibility that reduction patterns can be phonologically influenced by the type of $C_3$. Finally, previous analyses have relied simply on different rule ordering or free ranking between constraints in accounting for free variation, but have failed to capture the relative frequency of these variants.

This paper provides an Optimality Theoretic account of free variation in tri-consonant cluster reduction. The goal of this paper is three-fold. The first goal is to show, based on data collected from 8 Seoul speakers, that there is substantial intra-dialectal variation in consonant cluster reduction, which is far more complicated than has been previously discussed. Second, building on Jun's (1995, 1998) phonetically-driven OT account, this paper provides further evidence of the role of phonetic (especially perceptual) factors in determining complex consonant reduction patterns. In doing so, relationship between tri-consonant reduction and place assimilation will be also explored. Finally, this paper shows that the relative frequency of the variants can be correctly captured by the Gradual Learning Algorithm (Boersma & Hayes 1999) in which constraints are ranked stochastically on a continuous scale with possibly overlapping values.

### 1.1. *Jun's (1995, 1996, 1998) Phonetically-driven constraints*

In general, phonetically-driven constraints are based on the idea that speech production is governed by two possibly conflicting principles: ease of articulation and ease of perception. The principle of ease of articulation can be used to motivate the consonant cluster reduction, as expressed by Jun's constraint WEAK in (3):

(3) WEAKening constraint: Conserve articulatory effort
(= *Gesture) (from Jun 1998: 383)

This effort minimization constraint penalizes any candidates in a gradient fashion: the more consonants there are in the consonant cluster, the more severely the candidate is penalized.

The second type of constraint proposed by Jun is a type of faithfulness constraint that preserves perceptual cues as in (4):

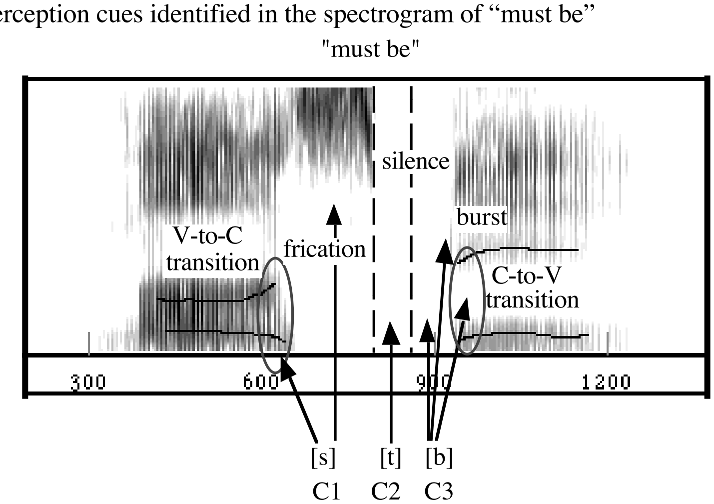
(4) Preservation constraint (from Jun 1998)
PRES(X): Preserve perceptual cues for place, manner, and other properties of a segmental class X.

In order to illustrate preservation constraints, let us look at an example of perceptual cues for each member of the consonant cluster /stb/ in the English phrase "must be" listed in (5) & (6). The spectrogram shows robust perceptual cues such as V-to-C formant transitions and high frequency frication noise for the postvocalic $C_1$ /s/, and C-to-V transitions, burst, and silence for the prevocalic $C_3$ /b/. On the contrary, the medial consonant $C_2$ /t/ has silence as its only cue. It is this perceptual weak segment /t/ that is often reduced in casual speech.

(5) Perceptual cues of the cluster *stb* in "must be" (from Jun 1998)

| C's | Context | Perceptual cues |
|---|---|---|
| b | t_i | release burst, C-to-V transitions, silence, (voicing) |
| s | u_t | frication, V-to-C transitions |
| t | s_b | silence |

(6) Perception cues identified in the spectrogram of "must be"




It has been suggested that speakers prefer to preserve perceptually strong segments (e.g., $C_1$ and $C_3$ in the figure) over perceptually weak segments (e.g., $C_2$). This has been called "Production Hypothesis" (Kohler 1990, 1991, 1992, Steriade 1993, Byrd 1994, Jun 1995, 1998), and is summarized in (7):

(7) Production Hypothesis
Speakers make more effort to preserve the articulation of speech sound with powerful acoustic cues, whereas they relax in the articulation of sounds with weak cues. (Jun 1995:29)

Put differently, speakers tend not to make an effort to preserve perceptually weak segments at the expense of perceptually strong segments; but rather speakers prefer to make an effort to preserve perceptually strong segments. In short, “speakers make more effort for those sounds which will produce dividends in terms of enhanced perceptibility” (Jun 1995:29). Following the Production Hypothesis, Jun proposed that the preservation constraints on consonants which adjacent to vowels must be ranked higher than constraints on consonants flanked by other consonants. This is shown in (8):

(8) PRES (C/V_C), PRES (C/C_V) >> PRES (C/C_C)

Jun also breaks down constraints according to place of articulation and proposes two additional universally applicable rankings which play a crucial role in place assimilation and consonant cluster reduction:

(9) a. Implicational Ranking I
PRES (k/V_C) >> PRES (p/V_C) >> PRES (t/V_C)

b. Implicational Ranking II
PRES (l/_t) >> PRES (l/_p) >> PRES (l/_k)

The ranking in (9a) is based on the assumption that alveolars have the weakest acoustic/perceptual cues (Ladefoged 1975, Kuehn & Mall 1976, Byrd 1994) while velars have the most robust cues such as compactness (e.g., Jacobson, Fant, & Halle 1963, Stevens 1989) and convergence of F2 and F3 in a neighboring vowel. Thus, constraints preserving acoustically more salient segments (e.g., /k/) are ranked higher than those preserving acoustically less salient segments (e.g., /t/).

The ranking in (9b) is ultimately tied to the idea that the acoustic/perceptual saliency of the first member of a consonant cluster varies depending on the inherent velocity of gesture of the following consonant. Jun argues that fast $C_2$ gestures influence $C_1$'s V-to-C transition less while slow gestures influence C1's V-to-C transitions more. Based on Kuehn and Moll’s cineradiographic data, which show that articulatory movement velocity increases in the order of tongue tip, lower lip and tongue body, Jun proposed that a constraint preserving /l/ before /t/ (with faster articulatory movement) is ranked higher than a constraint preserving /l/ before /k/ (with a slower articulatory movement).

Thus far I have summarized Jun’s phonetically driven constraints and their universally applicable implicational rankings. These constraints and rankings will serve as a base for phonological arguments made in this paper. In section 2, I will discuss how data were obtained; in section 3, results will be reported along with discussion based on Production Hypothesis and phonetically driven constraints introduced above; in section 4, I will show how the stochastic aspects of free variation can be captured in OT.

## 2. EXPERIMENT

As a native speaker of Seoul Korean, I have often thought that the variation in consonant cluster reduction is more complex than has been described by previous work. For example, in my own speech, the possible free variants for the underlying /lpt/ cluster include not only [l{p}t] and [lpt] (the possible variants for Seoul dialect described in the literature), but also a third possible variant [{l}pt]. This intuition motivated me to pursue a more systematic investigation of how tri-consonant clusters are realized in natural speech. This experiment was designed to test (1) what frequency each variant occurs at and (2) what conditions differences in frequency. A corpus was constructed based on the verbal stems in (10) and the verbal suffixes in (11).

(10) a. /ilk-/ 'to read'
b. /palk-/ 'to be bright'
c. /palp-/ 'to step on'
d. /nəlp-/ 'to be wide'
e. /halt$^h$-/ 'to lick'

(11) Verbal suffixes
a. -ta, -torok
b. -ci,
c. -ki, -ke, -ko
d. -nun, -ni, -na

These were combined to create words containing all of the target clusters listed in (12):

(12) a. /lk-C/: lk-t, lk-c, lk-k, lk-n
b. /lp-C/: lp-t, lp-c, lp-k, lp-n
c. /lt$^h$-C/: lt$^h$-t, lt$^h$-c, lt$^h$-k, lp-t

In order to minimize orthographic interference, the target word within a sentence was not written; instead, speakers were asked to recover it through the context after reading a model sentence (which was parallel to the target sentence) as shown in (13):

(13) a. **Model Sentence**
kɨnɨn **ɨmagɨl titt'a** malgo tʃamʃi mjəŋsaŋe tʃamgjətt'a
*'he stopped listening to music and was immersed in thought'*

b. **Target Sentence**
kɨnɨn **tʃægɨl** ('book')____ malgo tʃamʃi mjəŋsaŋe tʃamgjətt'a
*'he stopped ______a book and was immersed in thought'*

Each target sentence was recorded by 8 speakers with 6 repetitions in randomized order, yielding a total of 2160 tokens for analysis (5 verbal stems x 9 verbal suffixes x 8 speakers x 6 repetitions). Seven speakers were born in Seoul and lived there until they were in their twenties; one speaker was born in other city (Wonju, Kangwon) but she moved to Seoul before she entered elementary school and lived in Seoul until adulthood. Speakers were 28

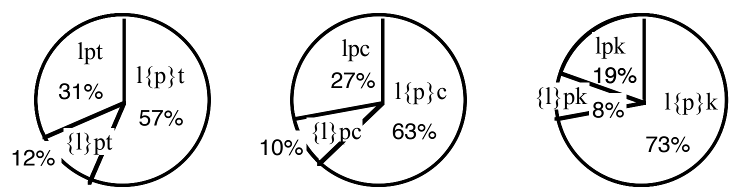
- 36 years old at the time of recording. The recorded materials were transcribed impressionistically from tape by the author with focus on the consonant cluster reduction.

## 3. Results and Discussion

The first result is that the prevocalic $C_3$ is never deleted. This supports the claim that consonants in syllable onset position are acoustically stronger than consonants in syllable coda position primarily because C-to-V transitions are acoustically/ perceptually more salient than V-to-C transitions (Bladon 1986, Ohala 1990, 1992, Jun 1995). In line with this, Jun (1995) suggests that the constraint preserving onset consonants is ranked higher than the constraint preserving coda consonants (i.e., PRES (onset) >> PRES (coda)).

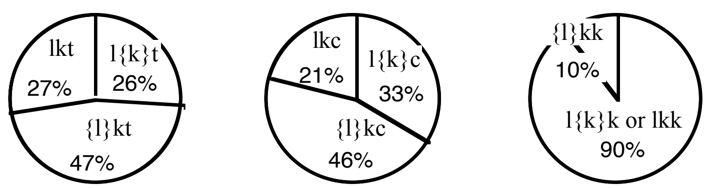
Another important result is that all three possible variants for /lp-C/ and /lk-C/ clusters occurred as shown in (14) and (15), contrary to the earlier general assumption that [{l}pC] and [l{k}C] do not occur in Seoul Korean.

(14) Frequency distribution of variants for /lp-C/ clusters



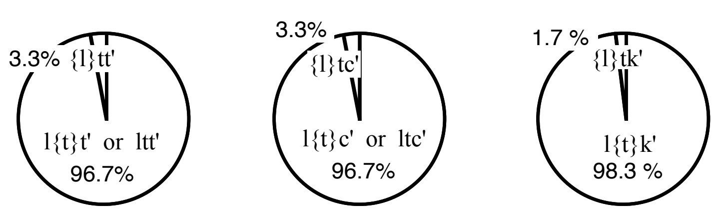

**a. /lp-t/** **b. /lp-c/** **c. /lp-k/**

(15) Frequency distribution of variants for /lk-C/ clusters




**a. /lk-t/** **b. /lk-c/** **c. /lk-k/**

(16) Frequency distribution of variants for /$lt^h$-C/ clusters



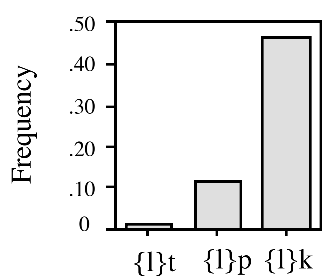

**a. /$lt^h$-t/** **b. /$lt^h$-c/** **c. /$lt^h$-k/**

This raises the question of why the medial consonant $C_2$ is sometimes preserved at the expense of $C_1$ when the constraint PRES (C/C_C) is ranked lower than PRES (C/V_C) as discussed in (8). This is because $C_1$ in our data is always [l] which has vowel-like formant properties so that /l/-to-$C_2$ transitions can serve as perceptually prominent cues, as also noted by Jun. Such transitional cues, together with silence, increases the perceptibility of the segment, and make it worth preserving.

### 3.1. *Variation and perceptual saliency of the target consonant*

As can be seen in (14)-(16), the frequency of occurrence varies depending on the place of articulation for $C_2$. If we exclude the case where $C_3$ is identical to $C_2$ for the moment (see below), $C_2$ (/p/) is deleted more frequently (57-63 % of the time) than $C_1$ (/l/) for /lp-C/ clusters, whereas $C_1$ (/l/) is deleted more frequently (46-47% of the time) than $C_2$ (/k/) for /lk-C/ clusters. For /lt-C/ clusters, $C_2$ (/t/) is deleted most of the time (97%). This pattern is illustrated in (17):

(17) Frequency of tokens with $C_1$ deleted



(Note: Data with C2=C3 are excluded)

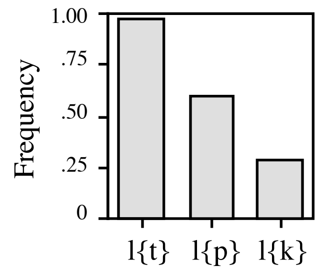
The frequency is greater for [{l}k], intermediate for [{l}p], and almost zero for [{l}t]. Such variation in frequency concurs with the prediction made by the Implicational Ranking I (9a) repeated here as (18), slightly modified by replacing V with /l/; namely that the perceptually more salient segment (/k/) is preserved more frequently and the perceptually weak segment (/t/) is preserved less frequently.

(18) Implicational Ranking I
PRES (k/l_C) >> PRES (p/l_C) >> PRES (t/l_C)

### 3.2. *Preservation of a consonant conditioned by the following consonant*

Data also suggest that variation in frequency of tokens preserving $C_1$ is conditioned by $C_2$. As seen in (14) - (16), $C_1$ (/l/) is most frequently preserved when $C_2$ is the alveolar /t/ (97%), but least frequently preserved when $C_2$ is the velar /k/ (29%). This point is summarized in (19):

(19) Frequency of tokens with $C_1$ (/l/) preserved




(Note: Data with C2=C3 are excluded)

This result agrees with Jun's claim that slower gestures for $C_2$ obscure the perceptibility of $C_1$ (/l/) more than faster gestures for $C_2$ do, and that, accordingly, the /l/ which is followed by the faster alveolar /t/ gesture is more worth preserving than /l/s followed by slower gestures (e.g., velar gesture). Implicational Ranking II, which encodes this phonetic explanation was given in (9b) and is repeated here as (20):

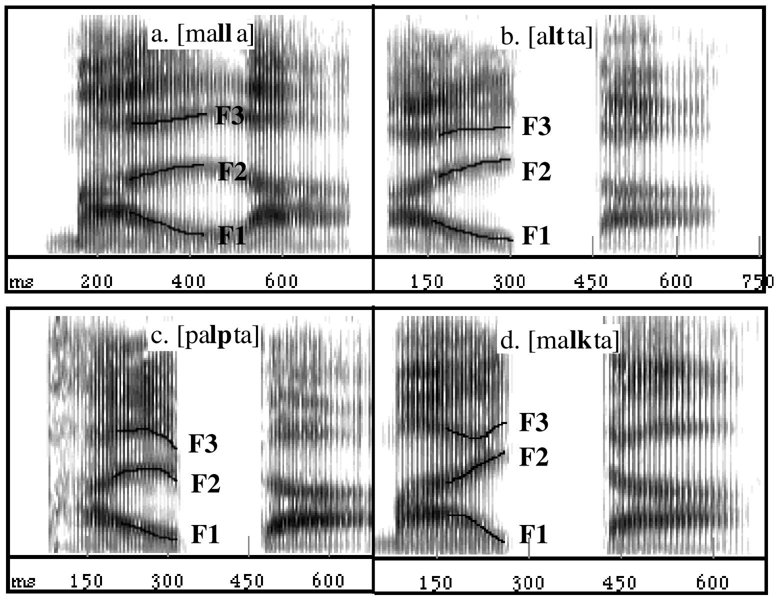
(20) Implicational Ranking II
PRES (l/_t) >> PRES (l/_p) >> PRES (l/_k)

The same explanation seems to hold for the influence of $C_3$ on $C_2$. Though our data do not provide a complete set for the comparison, /p/ is deleted more often before /k/ (73%) for /lp-k/ clusters than before /t/ (53%) for /lp-t/ clusters. This leads to another constraint ranking as in (21), which was not considered by Jun (1998). Just as $C_1$'s phonetic realization is influenced by the following $C_2$, so should $C_2$'s phonetic realization be influenced by the following $C_3$.

(21) Implicational Ranking III
PRES (C/l_t) >> PRES (C/l_p) >> PRES (C/l_k)

Now let us examine some sample spectrograms that illustrate the varying degree of $C_2$'s influence on $C_1$'s acoustic realization. Figure (22a) is a spectrogram for "malla" where two [l]s occur intervocalically. The traced portions of the spectrogram are estimated to be the first [l], which will be used as a base for the comparison between [ll], [lt], [lp], and [lk]. As can be seen in (22a), F1 gradually falls while F2 and F3 gradually rise. Similar transitional characteristics can be found in (22b) for [l] followed by the alveolar [t]. All three formant tracks resemble the control case of [ll]. Figure (22c) where [l] is followed by the bilabial [p] shows formant transitions a bit more deviated from the control case than they were for [lt]. Finally, as seen in (22d), the formant transitions for [l] followed by the velar [k] seem quite robust with the greatest deviation from the control case. These comparisons support the assumption that /l/ is least influenced when followed by the alveolar [t], and most influenced when followed by the velar [k]. Here one might raise a question of whether the differences come entirely from the velocity of the following C, as in Jun's position, or they have to do with the inherent differences in transitions for difference places of articulation. It is plausible that /t/ is least disruptive not because it is fastest, but rather because it is also the alveolar which has the least radical change in vocal tract configuration to get from /l/ to the alveolar. Although more systematic quantitative study is required to confirm the proposals, differences observed in the spectrogram seem at least suggestive in a same direction that the alveolar /t/ influences /l/ least.

(22) Formant structures of /l/ before different consonants




### 3.3. *Variation when $C_2 = C_3$*

When $C_2$ is identical to $C_3$ in place of articulation, the frequency of tokens preserving $C_2$ decreases drastically. As can be seen in (15) and (16), the frequency of tokens which delete $C_1$ (/l/) but keep $C_2$, is 10% for /lkk/ clusters and 3% for /ltt/ clusters. In other words, $C_1$ is preserved 90% of the time for the /lk-k/ cluster and 97 % of the time for the /lt-t/ cluster. This raises the question of why $C_2$ is preserved so infrequently when $C_2$ and $C_3$ share place of articulation. In Korean, stops in the $C_3$ position generally become tense (or geminated) before another obstruent (known as Post-Obstruent Tensification (Inkelas and Cho 1993, Han 1996). In addition, when $C_2$ is identical to $C_3$, the acoustic/perceptual properties of homorganic $C_2$ + tensified $C_3$ would be the same as those of the tensified (or tense) $C_3$ alone (cf. Oh & Johnson 1997) Here, the Production Hypothesis applies again; namely that speakers would not make an effort to preserve $C_2$ at the expense of /l/ since the effort would not pay off in enhancing the perceptibility. Therefore, speakers are reluctant to preserve $C_2$ when it is identical to $C_3$.

### 3.4. *Consonant cluster reduction and place assimilation*

Jun (1995, 1996) suggested that place assimilation is a result of gestural reduction rather than gestural overlap. This section examines the degree to which consonant cluster reduction and place assimilation are explained in common by acoustic/perceptual phenomena discussed in the preceding sections.

Jun's aerodynamic data show that /p/ in /pk/ cluster is reduced about half of the time while /p/ in /pt/ cluster is never reduced. Let us compare Jun's result with our data as summarized in (23):

(23) (assimilation )
  a. /pk/ → [{p}k] : 47 % (Jun, 1995)
  b. /pt/ → *[{p}t] : 0 % (Jun, 1995)
  (consonant cluster reduction when $C_2$= /p/)
  c. /lpk/ → [l{p}k]: 73 %
  d. /lpt/ → [l{p}t]: 53 %
  (consonant cluster reduction when $C_2$= /k/ or /t/)
  e. /ltk/ → [l{t}k]: 96 %
  f. /lkt/ → [l{k}t]: 26 %

The commonality between Jun's assimilation data (23a-b) and cluster reduction data (23c-d) is that /p/ is more prone to be reduced when followed by /k/ than when followed by /t/. This can be explained by the assumption that /k/ obscures the perceptibility of /p/ to a greater degree than does /t/, so that speakers are likely to preserve /p/ phonetically less influenced by the following consonant (i.e., /p/ before /t/). However, the influence of the following consonant cannot be the only source for the explanation of such variations since t/ is overall more likely to assimilate than /p/ is, regardless of the following consonant. For example, for (23e) (/ltk/ --> [l{t}k]) the deletion of /t/ 96% of the time is plausibly attributable to the interplay between the intrinsic acoustic/perceptual saliency of /t/ and the influence of the following /k/. That is, /t/ is least acoustic/perceptually salient and at the same time is strongly affected by the following /k/. Furthermore, the /t/'s weak acoustic/perceptual cues appears to be linked with the universal tendency of /t/ to assimilate to the following segment more than any other consonant (Cho 1990, Jun 1995). This suggests that consonants with greater assimilatory propensity are more prone to be reduced in consonant cluster simplification processes.

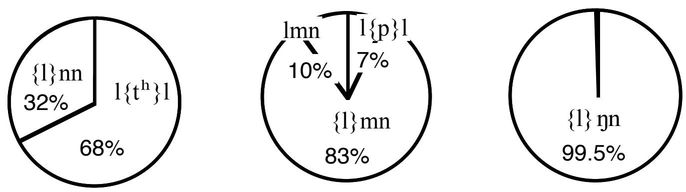
### 3.5. *Variations when $C_3$ is the nasal /n/*

In Korean, obstruents assimilate in nasality to a following nasal (e.g., /kak-mok/ → [kaŋmok]) and the alveolar nasal /n/ becomes lateral after a lateral (i.e., /n/-lateralization, /sil-nɛ/ → [sillɛ]). According to Kim-Renaud (1974), the tri-consonantal clusters /lt$^h$-n/ and /lp-n/ both become /ll/ due to the deletion of $C_2$ obstruents and subsequent lateralization of /n/ after /l/. In her analysis, obstruent deletion applies before the obstruent nasalization, so that (24a'-c') are not possible surface forms. (No discussion of free variation for /lt$^h$-n/ was provided in Kim-Renaud. However, if obstruent nasalization applies before obstruent deletion (with subsequent /l/-deletion), (24a'-c') would surface.)

(24) a. /lt$^h$-n/ → [ll]    a'. /lt$^h$-n/ → *[nn]
b. /lp-n/ → [ll]    b'. /lp-n/ → *[mn]
c. /lk-n/ → [ll]    c'. /lk-n/ → *[ŋn]

However, in our data, speakers *did* produce the supposedly not possible (or at least not previously mentioned) sequences in (24a'-c'). Figures (25) summarizes the relative frequency of free variants when $C_3$ is /n/:

(25) Frequency distribution of variants when $C_3$= /n/




a. /lt$^h$-n/    b. /lp-n/    c. /lk-n/

In general, the results seem to follow the basic patterns observed for the clusters with all oral consonants, although $C_2$ undergoes nasalization — namely, $C_2$ is preserved least frequently for the alveolar /t/ (32%), intermediately for the labial /p (83%), and most frequently for the velar /k/ (99.5%). Such variation agrees with patterns implied in Implicational Ranking I (18). Furthermore, the data also support Implicational Ranking II (20) — preservation of $C_1$ (/l/) is more frequent before /t/ (68%), intermediate before /p/ (17%) and almost null before /k/.

However, the patterns in resolving consonant clusters with the nasal /n/ in $C_3$ seem to be slightly different from those with all oral consonants, plausibly due to other phonological processes (i.e., prenasal nasalization and lateralization). What is different is that both lateralization (/lt$^h$-n/→ [ll]) and nasalization (/lt$^h$-n/ → [nn]) occur as in (25a-b). For (25a), the relative frequency of [ll] is greater (68%) than that of [nn] (32%). Recall that when $C_3$ is /t/, the relative frequency of tokens with /l/ being preserved is about 97% (see (16)). But the frequency drops to 68% when $C_3$ is /n/. Likewise, $C_1$ (/l/) is preserved about 50% for the /lk-t/ cluster and almost never for the /lk-n/ cluster.

The difference between these and all-oral clusters comes primarily from the phonotactic constraint that prohibits a sequence of [ln]. For the /lt$^h$-n/ cluster, if $C_2$ is reduced, then the result would be [ln] which is not allowable in the system. Consequently, preservation of $C_1$ /l/ (and deleting $C_2$ at the same time) can be done only through sacrificing the nasality of $C_3$ in the onset. This may be why $C_1$ is not preserved as often when $C_3$ is nasal as when $C_3$ is oral. Interestingly, however, there are still differences between the /lt-n/ and the /lk-n/ clusters. While the frequency of [ll] tokens is 68% of the time for the /lt$^h$-n/ cluster, [ll] never occurs for the /lk-n/ cluster. This asymmetry can be attributed to the Production Hypothesis that speakers make an effort to preserve acoustically and perceptually salient segment /k/. Preservation of /k/ with loss of /l/ has another motivation — namely that the /l/ has the phonetic cues obscured to a great degree by the following /k/ and thus is more likely to be reduced than the /l/ followed by /t$^h$/. Similarly, speakers preserve /l/ at the expense of /t$^h$/ not just because of the least influence by /t$^h$/ but also because of /t$^h$/'s greater propensity of reduction.

## 4. OT ANALYSIS OF FREE VARIATION

So far I have shown, building on Jun's analysis, that acoustic and perceptual phenomena play an important role as a source of explanation for the variations found in our data. In this section, I will attempt to show how such complex variation data can be captured in the framework of Optimality Theory.

Let us first take an example of OT analysis in which three variants for the underlying /lpt/ can be accounted for by three different rankings between crucial constraints as given in (26):

(26) a. *GESTURE, PRES(l/_p) >> PRES(p/l_C)

| lpC | *GESTURE | PRES (l/_p) | PRES(p/l_C) |
|---|---|---|---|
| a.√l{p}C | ** (2 Cs) | | * |
| b. {l}pC | ** (2 Cs) | *! | |
| c. lpC | **!* (3 Cs) | | |

b. *GESTURE , PRES(p/l_C) >> PRES(l/_p)

| lpC | *GESTURE | PRES (p/l_C) | PRES(l/_C) |
|---|---|---|---|
| a. l{p}C | ** (2 Cs) | *! | |
| b.√{l}pC | ** (2 Cs) | | * |
| c. lpC | **!* (3 Cs) | | |

c. PRES(l/_p), PRES(p/l_C) >> *GESTURE

| lpC | PRES (l/_C) | PRES(p/l_C) | *GESTURE |
|---|---|---|---|
| a. l{p}C | | *! | ** (2 Cs) |
| b. {l}pC | *! | | ** (2 Cs) |
| c. √ lpC | | | *** (3 Cs) |

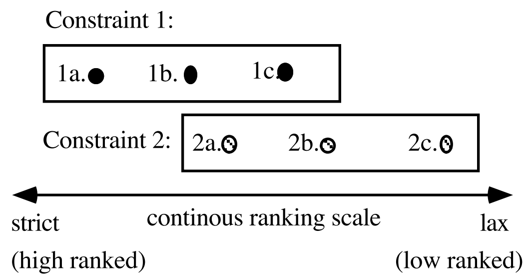
If the winner is [l{p}C], both *Gesture and PRES(l/_p) outrank PRES(p/l_C) (26a), but the opposite ranking is needed between PRES(l/_p) and PRES(p/l_C) for the winner [{l}pC] (26b). If the winner is [lpC] with no reduction, then *Gesture is demoted, being outranked by the preservation constraints (26c).

It has been a convention in OT to explain such free variation by free ranking between the relevant three constraints. This mechanism, however, does not capture the relative frequency of each variant and fails to explain how such free variation is grammaticized in the language. In what follows, I will show that the stochastic aspect of the free variation can be captured in OT by the "Gradual Learning Algorithm" developed by Boersma (1997), and Boersma & Hayes (1999).

### 4.1. *Gradual Learning Algorithm (GLA)*

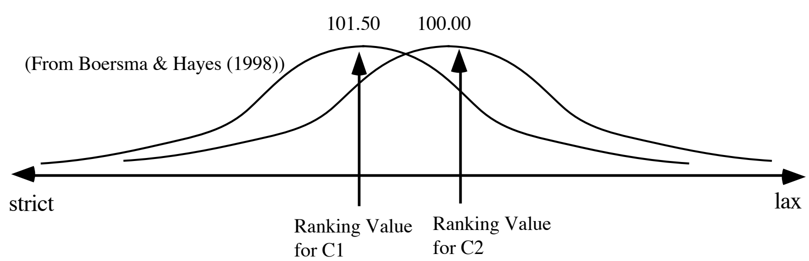
The basic idea of the Gradual Learning Algorithm (Boersma & Hayes, 1999; Boersma 1997) is that constraints are ranked on a continuous scale. Each constraint is assigned a probability distribution (i.e., a range of possibly overlapping values) along this scale. Free variation occurs when there is overlap between these distributions, allowing the grammar to generate multiple outputs for a single input. Figure in (27) depicts how distributions of two constraints overlap, resulting in free variation:

(27) Ranges with overlap




At evaluation time, speakers choose the precise location of the constraints from anywhere within their ranges. If a speaker chooses point (1a) for Constraint 1 and any point for Constraint 2, the result will be C1 >> C2. If a speaker chooses point (1c) for Constraint 1 and point (2a) for Constraint 2, the reverse ranking, C2 >> C1, will hold. In the Gradual Learning Algorithm, each constraint has probability distribution and ranking value which is the mean of its affiliated normal distribution, as illustrated in (28):

(28) Overlapping normal distributions



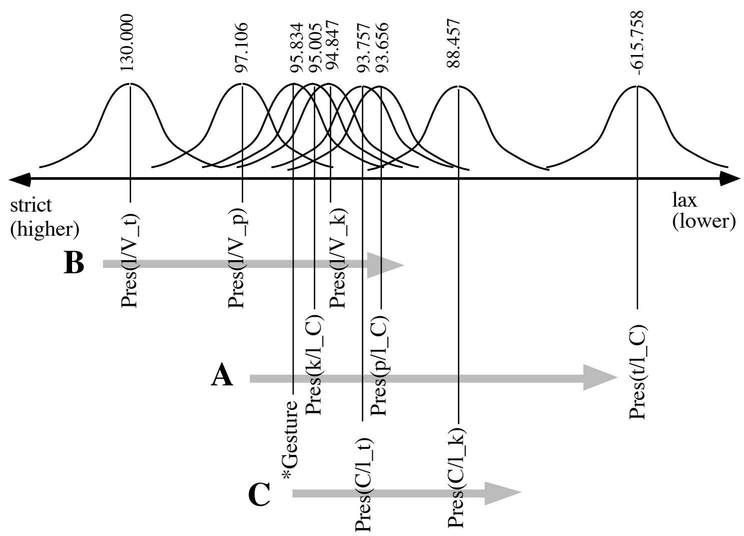

In the figure, the difference between ranking values (101.50 and 100.00) is 0.5, meaning two distributions are 0.5 standard deviation apart. Such overlapping normal distribution curves can generate multiple outputs. Since the range of Constraint 1 is overall higher than the range of Constraint 2, the probability of occurrence of the output generated by C1 >> C2 ranking is greater than that generated by C2 >> C1.

4.2. *Frequency matchup by GLA*

The Gradual Learning Algorithm employs simultaneous demotion and promotion of ranking values (starting with an arbitrary default value, 100.000), until the ranking values reach the point at which the relative frequencies generated by the grammar maximally matches the input frequencies. Figure (29) shows the frequency matchup generated by the GLA for the inputs, /lp-t/, /lp-k/, /lk-t/ & /lt$^h$-k/.

In the figure, the constraints are grouped into three different categories, as marked by arrows. The relevant constraints are grouped by arrow A into Implicational Ranking I (18), by arrow B into Implicational Ranking II (20), and by arrow C into Implicational Ranking III (21). Actually the system endowed with this ranking would produce forms in the same frequency as actual Seoul speakers with 4.5 % error.

(29) Frequency matchup by GLA for the inputs, /lp-t/, /lp-k/, /lk-t/ & /lt$^h$-k/.




What is generated by the GLA reliably captures the stochastic aspects of free variation found in this study. Note that this is done by overlapping probability distributions of constraints. The complicated and variable pattern of tri-consonantal cluster simplification in Korean demands a complicated and subtle analysis, employing a variety of phonetically-motivated constraints, and a flexible way to rank them, as that provided by the GLA.

## 5. Conclusion

Our data showed that variation in cluster simplification in Seoul Korean is far more complicated than has been previously discussed. I argue that this variation is conditioned primarily by phonetic properties of the members of the consonant cluster. A complex pattern arises from interplay between phonetically motivated factors. One source of complexity which I have explored here comes from implicational rankings, which prefer to preserve consonants in some environments more than others. The phonetically driven constraints and their implicational rankings account for both the assimilation data (Jun 1995) and the tri-consonantal data in this study. This suggest that there may be a close relationship between tri-consonant reduction and assimilation, both of which may be handled by the same basic phonetic motivations. Finally, I showed that the complex stochastic aspect of a variation in the consonantal cluster simplification requires a sophisticated and subtle analysis, rather than simply manipulating rankings between constraints.

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