AN ULTRASOUND STUDY OF COARTICULATION AND VOWEL ASSIMILATION IN KOREAN*

Gwanhi Yun
University of Arizona

Ultrasound imaging experiments were conducted to study vowel-to-vowel coarticulation patterns involving the environment of vowel assimilation in Korean. Results showed that anticipatory coarticulatory effects occur and that vowel assimilation is truly phonological and that the degree of coarticulation is stronger in assimilated words than in non-assimilated words. These results imply that phonological rules might directly influence coarticulation in a phonology-phonetics unified grammar.

1. Introduction

The aim of this paper is to attempt to see through untrasound imaging studies whether or/and what types of vowel-to-vowel coarticulation might occur in case of vowel assimilation in Korean. Specifically there is a well-known optional phonological process in Korean, whereby back vowels such as /► , a, u, o/ become front vowels [e, ɛ, y, ø] before a front vowel /i/ as in (2). This process is optional and occurs among older people and uneducated people and is not considered as standard (Sohn 1999). In addition, even younger people or users of standard Seoul dialect utter the assimilated forms in casual style conversations. Korean vowel system and i-vowel regressive rule are illustrated in (1) - (3).

(1) Vowel system (Sohn 1999; 156)

place	front		back	
lips	unround	round	unround	round
tongue				
high	i	y(wi)	ɨ	u
mid	e	Ø(we)	ə	o
Low	ɛ		a	

* Thanks to Diana Archangeli, Michael Hammond, Bob Kennedy, and Jeff Mielke for their invaluable comments and help. I am also grateful to the colleagues in LING 696 Phonology Seminar Spring 2004, University of Arizona for their discussions and feedback. All errors are of course mine.

Coyote Papers 14, 196-216
Linguistic Theory at the University of Arizona
© Gwanhi Yun

(2) /ə, a, u, o/ → [e, ɨ, y, ø] / ___ + i

(3) Assimilated forms vs. Unassimilated forms

a. *Input*	b. *Assimilated form*		c. *Unassimilated form*	d. *Gloss*
/məki/	[megi]	~	[məgi]	'prey, food'
/əmi/	[emi]	~	[əmi]	'mother'
/holangi/	[hoɾaŋi]	~	[hoɾaŋgi]	'tiger'
/koyangi/	[koyaŋi]	~	[koyaŋi]	'cat'
/aki/	[ɛgi]	~	[agi]	'baby, child'
/hakkyo/	[hɛkk'yo]	~	[hakk'yo]	'school'
/cwukita/	[cwygida]	~	[cwugida]	'kill'
/nwuphita/	[nwyp^{h}ida]	~	[nwup^{h}ida]	'lay'
/nokita/	[nøgida]	~	[nogida]	'make..melt'
/koki/	[køgi]	~	[kogi]	'meat'

The first question is whether the unassimilated back vowels in (3c) affect the frontness of the front vowel /i/. If this kind of vowel-to-vowel carryover effects occur, the front vowel /i/ in (3c) would be articulated in farther backward in the vicinity of palatal zone in comparison with the normal position of /i/.

The second question is whether the front vowel /i/ in unassimilated forms (3c) affects the backness of the preceding back vowels. If this type of vowel-to-vowel anticipatory coarticulation takes place, we would expect that those back vowels would be produced in more forward in comparison with those in monosyllabic words such as /mək/.

The third question is involved with the phonological status of the above vowel assimilation rule. The targets (e.g. /e/) in assimilated forms (3b) are compared with those in isolation forms. If the result of this harmony is a set of segments identical in articulation to the corresponding unassimilated front vowels, it might indicate that the rule is phonological but if it is not, it might be phonetic.

The last question is whether the assimilation rule influences the degree of coarticulation. By answering these four questions, we will discover some important implications as to Korean vowel interactions. First, we will know that V-to-V coarticulation also co-occurs with the well-known phonological assimilation with respect to i-vowel regressive assimilation (2) if we get significant results in the last question. Secondly, by answering the first and second question,

we might know about the directionality of coarticulation, i.e. if the V-to-V coarticulation is either carryover effect or anticipatory effect. The previous literature surveys that the front vowel /i/ is more resistant to V-to-V coarticulation than other vowels across the dorsal consonants because of its highly constrained gestures. Thus, this phonetic study through the ultrasound machine will reveal whether Korean vowel coarticulation might confirm such observation. The last question will tell us about the interaction between phonological rules and coarticulation.

2. Hypotheses

First, as for the first and the second question, there has been much research on the effects of segmental internal articulatory properties on coarticulation. Particularly Recasens *et al* (1997) suggested the notion of degree of articulatory constraint (DAC) on the basis of how actively tongue dorsum is involved in articulation. For example, according to DAC, dorsals (i.e. alveopalatals, palatal /i/, velar /k/, dark /l/) are articulated with active tongue dorsum raising toward the palatal zone where they cause large amounts of contact (Recasens 1990: Recasens and Romero 1997). Dorsals are assigned DAC 3, which means that they are the most resistant to coarticulation. DAC 2 is assigned to alveolars /n/, /s/ and low back vowel /a/, while DAC 1 to labials and schwa. Thus, on this segment internal gestural strength, the following hypothesis is proposed.

(4) "No carryover effect" hypothesis

> The front vowel /i/ in the unassimilated forms would not be articulated in farther backward in the vicinity of palatal zone in comparison with the normal position of /i/.

Assuming that /i/ is considered the most resistant to coarticulation, carryover effects will not occur. In relation to the directionality of coarticulation, if no carryover effects are given, we can suggest the following hypothesis as DAC expects.

(5) "Anticipation effects" hypothesis

> The back vowels in unassimilated words would be produced more forward as an influence of the following front high /i/.

Turning to the assimilated forms, even though this i-vowel regressive assimilation is optional, it involves the featural change from [+back] to [-back].

That is, it is reasonable to think that the articulation of the assimilated back front vowels reflect this categorical change. Thus the following hypothesis is set forth.

(6) "Phonological status" hypothesis

> The assimilated front vowels may be almost the same as the unassimilated front vowels in terms of frontness of tongue body because of the application of a phonological rule.

Last, but not least important one is about the direct influence of this vowel harmony rule on low-level coarticulation. Aside from a unified model of phonetic-phonology model (Flemming 2001), there have been put forth considerable research where it is difficult to make a clear distinction between phonological component and phonetics component. The boundary between phonological rules and phonetic implementation may not be clear, but rather they interact with each other. Following that assumption, in this study it may make sense to come up with the following hypothesis.

(7) "Phonological enhancement of coarticulation" hypothesis

> The degree of coarticulation may be stronger in the front vowels in assimilated words than in those of unassimilated words.

That is, the front vowels in assimilated words may be articulated more forward than those in nonassimilated words because of the facilitation of the vowel assimilation rules. Of interest is that if the significant difference between these two types of front vowels, it will be another supportive evidence that high-level phonological rules enhances the degree of low-level phonetic fine detail coarticulation. Further step may be the attempt to incorporate constraints responsible for the low-level phonetics into the phonological component.

3. Experiments

Subjects

In total, four native speakers of Korean participated in production of Korean words to take ultrasound imaging pictures of their tongue movements. They were randomly chosen among the undergraduate or graduate students at the University of Arizona or in the campus community. The age of the subjects ranges from 20 to 30. Two subjects are female, and the other two are male. Further, two are Seoul standard dialect speakers and two are speakers of other regional dialects.

Materials

First, only real Korean words which contain a sequence of a vowel and a consonant and a front vowel /i/ was employed whether they consist of two or three syllables. What needs to be noted is that the intervocalic consonant was fixed as a velar such as /g/ or /ŋ/ in order to reduce the influence of the consonant on vowel interaction. In fact, it is known that laminodorsal and dorsals are more resistant than apical and laminal consonants to vowel-dependent effects at the place of articulation partly due to their involving a large closure or constriction with a sluggish tongue dorsum articulation (Recasens 1999). Thus, it will be helpful to use the real words with the intervocalic dorsal (or velars) to see the extent of only vowel coarticulation across a consonant as clearly and accurately as possible. Each word was recorded five times to get more reliable statistical generalization.

With regard to the testing of first hypothesis, it is necessary to see the extent of frontness of /i/ in the unassmilated forms in comparison with the frontness of /i/ in the monosyllabic forms such as /ki/ 'flag' as is shown in (8). Since the focus is on the comparison of the frontness of /i/ on both forms, we will measure the overall frontness or backness of the tongue body of the front vowel through the ultrasound pictures.

(8)

a. *Test word*				b. *Control word*	
/məki/	[məg**i**]	'prey, food'	~	[k**i**]	'flag'
/nuləngi/	[nuɾəŋ**i**]	'yellow dog'			
/holangi/	[hoɾaŋ**i**]	'tiger'			
/aki/	[ag**i**]	'baby, child'			
/cwukita/	[cwug**i**da]	'kill'			
/nokita/	[nog**i**da]	'make..melt'			
/koki/	[køg**i**]	'meat'			

Next, since the second hypothesis is to see if there are V-to-V anticipation effects, we will look into the extent of backness of the back vowels in the unassimilated forms. Thus, the frontness of the back vowels in the monosyllabic words such as /m► k/ will be measured for comparison with the back vowels in the test words as in (9). In this case also, the frontness or backness of the overall tongue body will be measured with respect to the back vowels to see the backness of the V_1 in the V_1Ci.

(9) a. *Test word* b. *Control word*

/məki/	[m**ə**gi]	‘prey, food’	~	[m**ə**k]	‘painting stuff’
/nuləngi/	[nuɾ▶ ŋi]	‘yellow dog’		[l**ə**ŋ]	
/holangi/	[hoɾ**a**ŋi]	‘tiger’		[l**a**ŋ]	
/aki/	[**a**gi]	‘baby, child’		[**a**k]	
/cwukita/	[cw**u**gida]	‘kill’		[cw**u**k]	
/nokita/	[n**o**gida]	‘make..melt’		[n**o**k]	
/koki/	[k**ø**gi]	‘meat’		[k**ø**k]	

Since the third hypothesis is to test to see if there might be significant phonetic differences between the assimilated front vowels and unassimilated back vowels V_1s in *V_1Ci*, we need to measure the backness of front vowels in assimilated forms in (10). And then it is necessary to compare it with the backness of the vowel in isolation form in (10c). If the result of comparison reveals that the articulatory property of the front vowels is not significantly different from that in isolation form, it indicates that the assimilations rule is phonological, not phonetic. Like the previous two cases, the position of the overall tongue body will be measured through the ultrasound pictures.

(10) a. *Assimilated Form* b. *Gloss* c. *Control word*

[m**e**gi]	‘prey, food’	[m**e**k]
[nwu▶ **e**ːi]	‘yellow dog’	[l**e**ŋ]
[ho▶ **ɛ**ŋi]	‘tiger’	[l**ɛ**ŋ]
[koy**ɛ**ŋi]	‘cat’	[y**ɛ**ŋ]
[**ɛ**gi]	‘baby, child’	[**ɛ**k]
[cw**y**gida]	‘kill’	[cw**y**k]
[n**ø**gida]	‘make..melt’	[n**ø**k]

To test the last hypothesis, the frontness of tongue body of the front vowels in assimilated forms (11a) were compared with that of the same front vowels in unassimilated forms (11b).

(11) a. *Assimilated Form* b. *Control Word*

[me**ɐ**gi]	/me**ɐ**ki/	'catfish'
[nu**►** e**ɐ**ŋi]	/kə**ɹ**e**ɐ**ŋi/	'beggar'
[ho**ɹ**e**ɐ**ŋi]	/koore**ɐ**ŋci/	'high, cool land'
[**ɛ**gi]	/t**ɛ**ki/	'signs of pregnancy'
[c**ɣ**gida]	/**ɣ**ki/	'crisis'
[n**ø**gida]	/n**ø**kin**ɪ**ŋ/	'brain function'

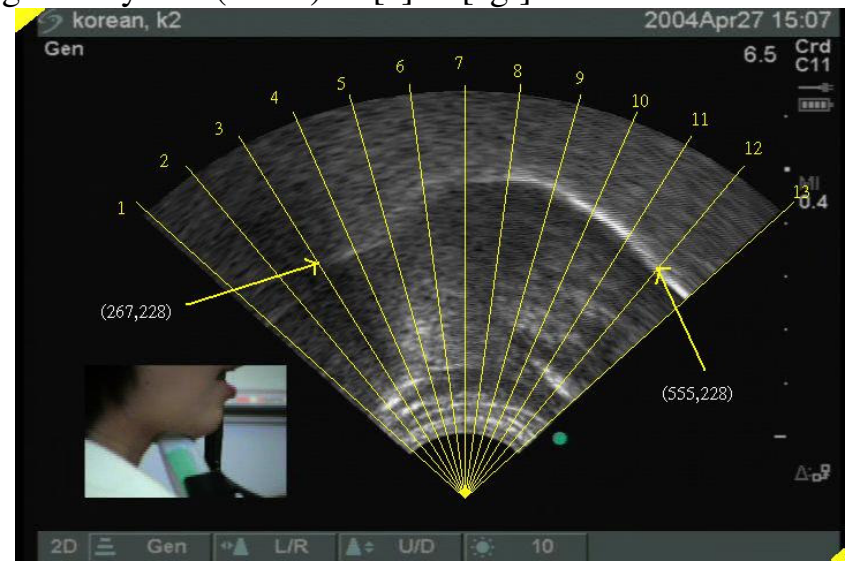
Design

Test words and control words were displayed on a monitor screen in front of the subjects in the isolation forms. Each token word was uttered five times from each subject. In total, 775 tokens of words were produced from 4 native subjects, but the images of one speaker were excluded from analysis because of unclear images and difficulty to measure the tongue line. So 495 tokens of images were analyzed.

Procedures

Ultrasound machine were utilized in the phonetics lab in the department of Linguistics at the University of Arizona. The frontness or (backness) of the tongue body was measured on the basis of the taken ultrasound imaging and recorded in the computer in the videotapes. In a sequence of V_1-C-V_2, the intervening velar consonant was not measured, but only the tongue position of surrounding vowels on both sides was measured. Specifically, let us look at the example of an ultrasound picture in (12). First, in order to quantify the tongue shape, a concentric radial grid was placed over the ultrasound images which are marked with pixels. Then, the values of x, y, coordinates were measured at about ten points along the tongue shape line. The units for (x.y) values are pixels set in the images. These original data are readjusted with the relevant formulae (i) to bring the tongue outline closer to the x-axis and y axis in the graph, and to invert the tongue. (If you had just plotted the tongue with the basic x,y coodinates, it would appear upside down, because the y values increase from top to bottom in the jpeg images). And then the average of 5 tokens is calculated in 10 points of tongue shape. These adjusted averages create the smooth tongue body line with Excel program.

(12) The tongue body line (white) of [a] in [agi]



tongue root (back) ← → tongue tip (front)

4. Results

4.1 "No carryover effect" hypothesis

Fig. 1 and Fig. 2 show the tongue body lines of [i] in /ki/ and [i]s in unassimilated words. There was not significant difference in the backness of tongue body between [i] in /ki/ and [i]s in other unassimilated forms in K 1 speaker (at two points 5th and 6th vectors, respectively, p=0.52, p=0.41) as in K2 and K3 speakers. These results confirm "no carryover effect" hypothesis that the front vowels in unassimilated forms are not affected by the preceding back vowels. The finding of significantly less variation of the front high /i/ following back vowels also supports the notion of degree of articulation constraint. That is, when a V-to-V sequence arises, the directionality of coarticulation may be determined in some extent by the coarticulation resistance of each vowel.

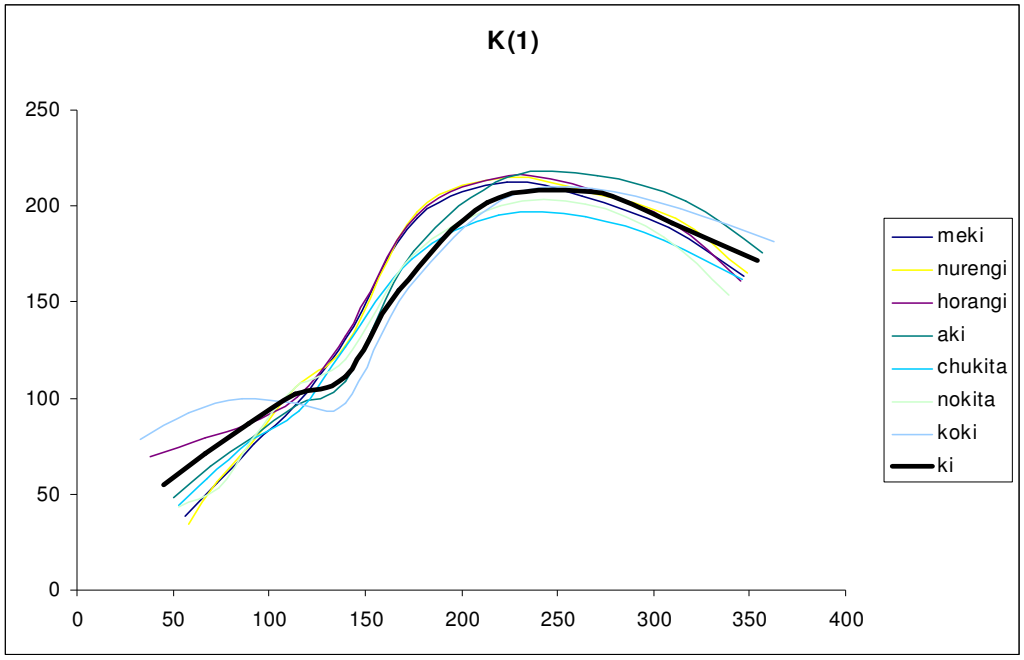


Fig.1. Tongue body shapes of [i] in /ki/ (darker line) and [i]s in the unassimilated words in K1 speaker.

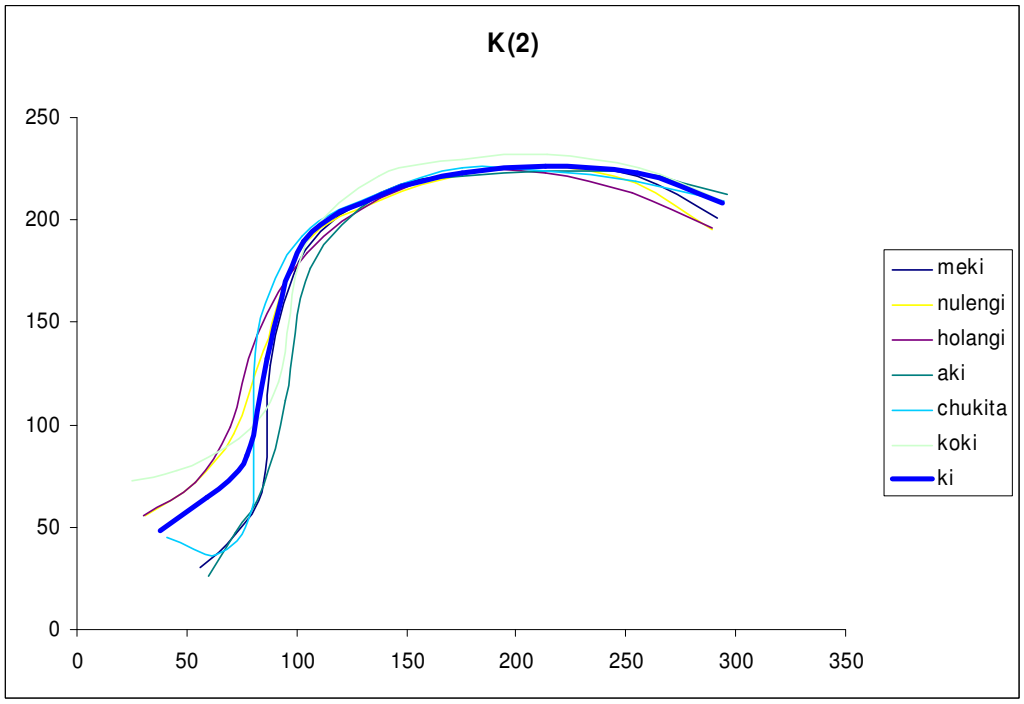


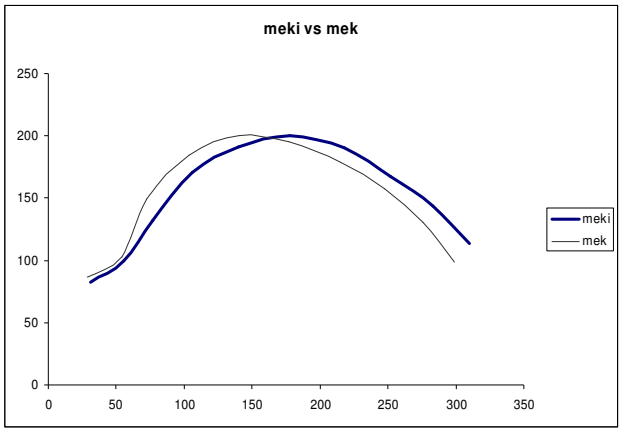
Fig.2. Tongue body shapes of [i] in /ki/ (darker line) and [i]s in the unassimilated words in K2 speaker.

Since the compared words are all real words in the above, we do not see the effect of lexical status on coartiuclation. Further, because of large difference of the size of oral cavity and tongue length as well as lack of technical problems in measuring individual variability, we could not see an analysis of variance (ANOVA) to investigate the influence of sex on the degree of coarticulation.

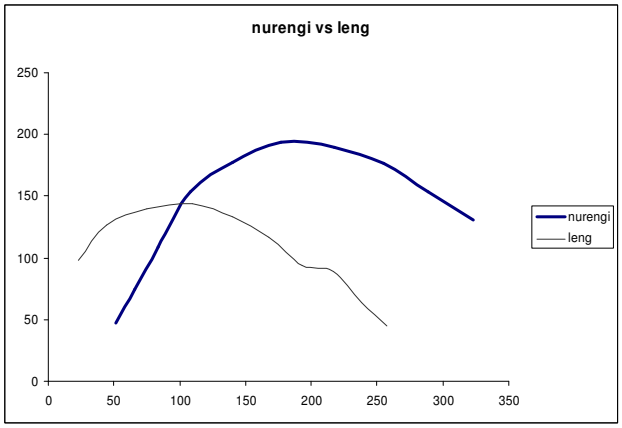
4.2 "Anticipation effects" hypothesis

Fig. 3 shows the relative tongue body positions of back vowels in unassimilated forms and of back vowels in control monosyllabic words. There was considerable difference in tongue frontness between back vowels followed by front vowel /i/ and back vowels in monosyllables. However, there was not considerable variation between subjects. Rather, three speakers showed the consistent pattern even along with an exceptionally nonsignificant difference in the case of /meki/ vs /mek/ (see Fig. 3(a)) as K 1 speaker's tongue body positions, which are illustrated in Fig. 3.

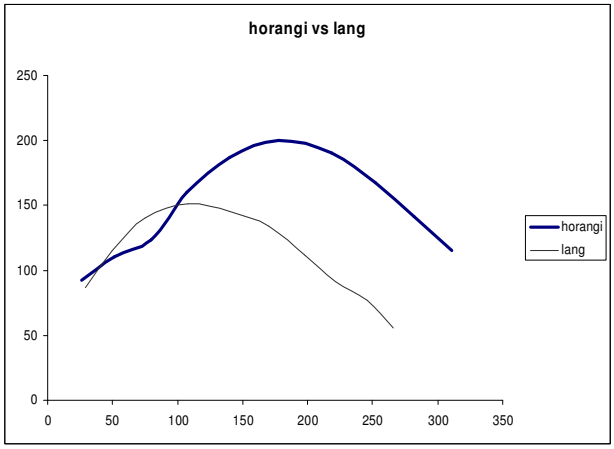
a. [m▶ gi] ~ [m▶ k]



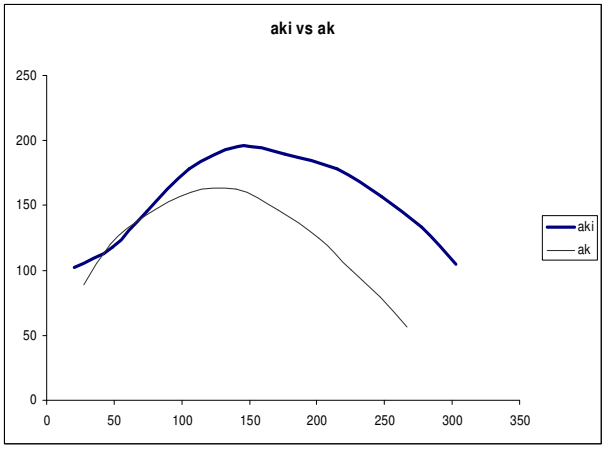
b. [nuɾ▶ ŋi] ~ [l▶ ŋ]



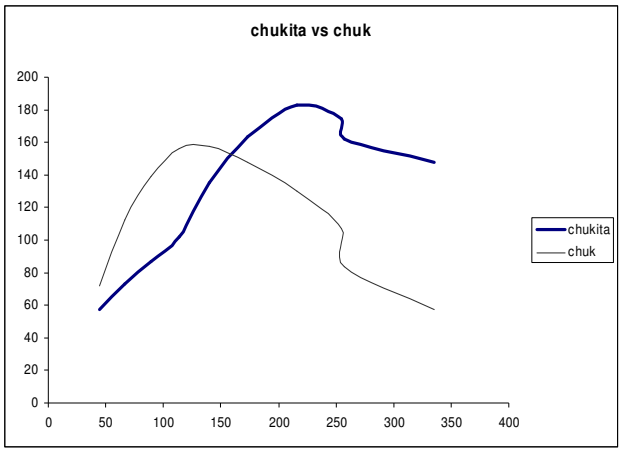
c. [hoɾaŋi] ~ [laŋ]



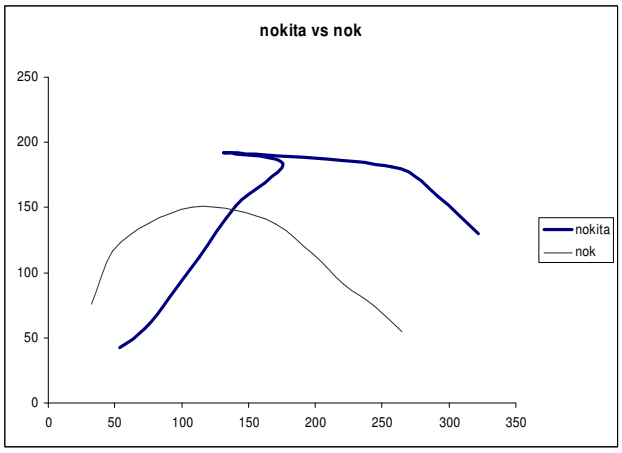
d. [agi] ~ [ak]



e. [c**u**gida] ~ [c**u**k]



f. [n**o**gida]~ [n**o**k]



g. [k**o**gi] ~ [k**o**k]

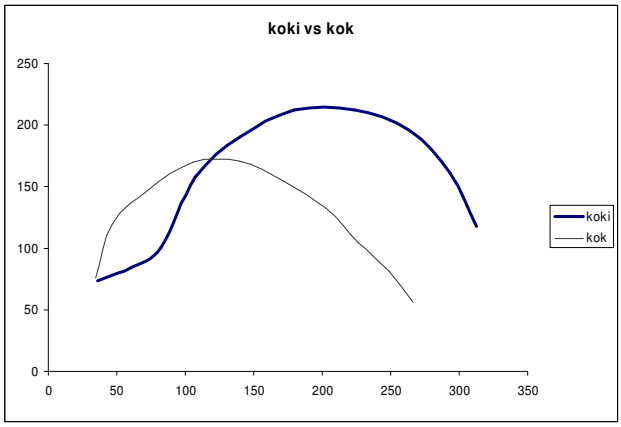


Fig. 3. Tongue body shapes of back vowels in unassimilated forms (darker lines) and corresponding back vowels in control words (lighter lines) of K1 speaker.

First, we found that back vowels with the following front vowel /i/ were articulated further forward than back vowels with no following vowels in monosyllable words. These results confirm the "anticipatory effect" hypothesis that back vowel are coarticulated with the following high front vowel /i/. They are exactly what we predicted on the basis of comparison of degree of articulatory constraints. High front vowel /i/ shows the highest DAC, which is assigned 3. So According to DAC, when a sequence of high front /i/ and low or mid vowels arise, high front /i/ shows the most resistance to coarticulation, but rather low or mid vowels are likely to undergo coarticulation from the influence of the high front /i/. And even though the degree of anticipation effect is less prominent in the case of /m► ki/ vs /m► k/, it still shows an anticipation effect. Further, one speaker (K3) showed a little different pattern in the cases of /koki/ vs. /kok/ and /chuki/ vs. /chuk/. That is,

because of the reason that is difficult to explain, the back vowels /o/ and /u/ followed by /i/ were articulated farther backward than those in monosyllable words.

Second, Fig. 3 shows that the back vowels preceding the front high vowel was also considerably higher articulated than those in monosyllable words. However, it was difficult to measure how much the vowel height was correlated with whether the back vowel was low, mid, or high.

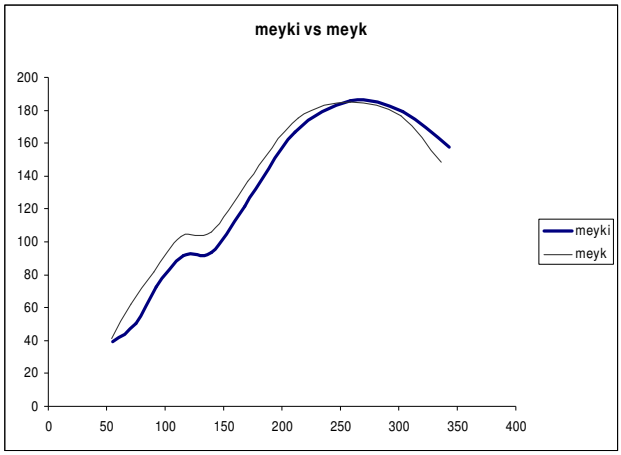
In summary, we found that in this particular assimilation environment, V-to-V coarticulation is mostly anticipatory (right-to-left), not carryover (left-to-right). There was neither sex difference nor vowel height variation correlated with the degree of coarticulation. These anticipatory effects are mostly consistent with the prediction of degree of articulatory constraints which are based on vowel internal coarticulation sensitivity. Thus, our study confirms "anticipation" hypothesis and "no carryover" hypothesis.

4.3 "Phonological status" hypothesis

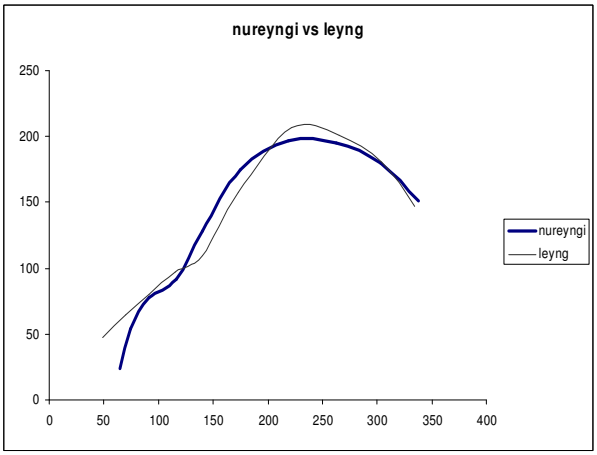
Fig. 4 displays the tongue body positions of the assimilated front vowels and the front vowels in monosyllables. On the assumption that the application of a phonological rule such as vowel regressive rule changes the feature [+back] into [-back] categorically, we expected that the front vowels in the assimilated forms would be articulated as much in the same position as those in nonsense monosyllabic forms. The darker lines refer to the tongue body shapes of front vowels in the assimilated forms and lighter ones to the tongue body shapes of front vowels in control words. The figure shows that the position of front vowels in the assimilated words is not considerably different from corresponding front vowels in monosyllable forms. Specifically, in (a,d,e,f), the front vowels /e/,/ɛ/,/ø/, and /y/ seem to be articulated a little more forward than the same vowels in nonsense forms as a result of an anticipatory effect from the trigger vowel /i/. However, the difference is not large. In addition, even though in (b,c), the front vowels /e/ and /ɛ/ seem to be articulated farther backward than the same vowels in nonsense words, the difference is not considerably large. That is, we found the inconsistent difference in the frontness of tongue body between two types of the front vowels. The other two Korean speakers also show the nonsignificant differences between the assimilated front vowels and the front vowels in nonsense forms in terms of backness although the degree is a little variant. One speaker also showed unexpected, inconsistent pattern with the other word pairs. That is, the female speaker articulated the front vowel /ɛ/ in /horɛngi/ farther backward than the same

/ɛ/ in /lɛŋ/. This is in agreement neither with the typical anticipatory coarticulation, nor with any natural phonetic phenomena. Similar to the results on previous two hypotheses, it was difficult to find any across-subjects correlation with the degree of coarticulation such as the factor of sex on the degree of coarticulation.

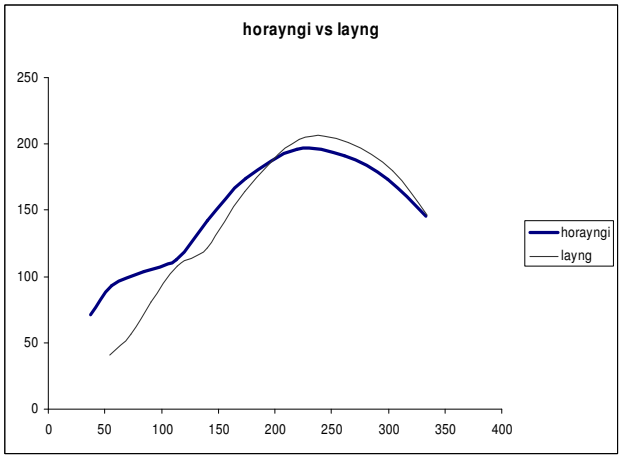
a.[m**e**gi] ~ [m**e**k]



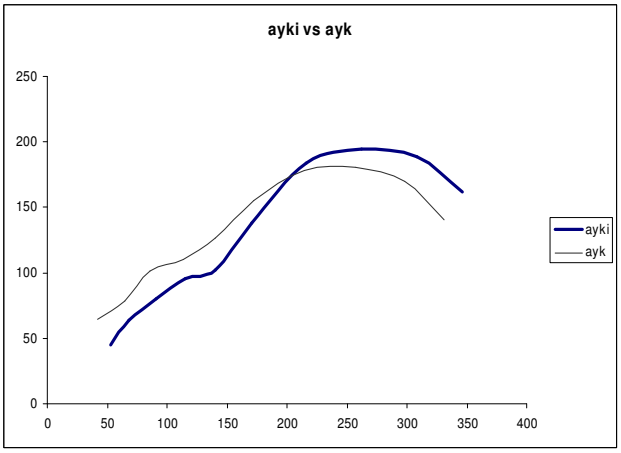
b. [nuɾ**e**ŋi] ~ [l**e**ŋ]



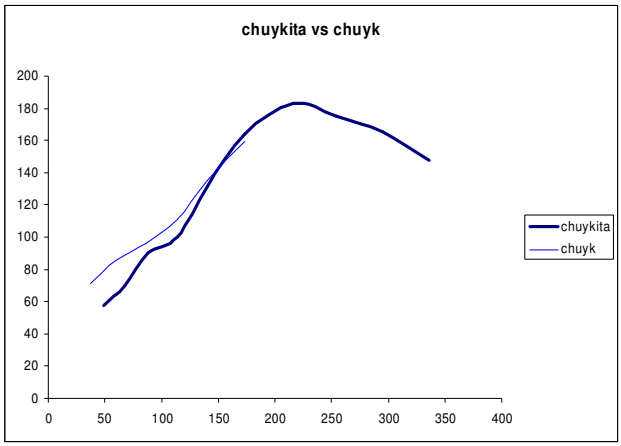
c. [hoɾ**ɛ**ŋi]~ [l**ɛ**ŋ]



d. [**ɛ**gi] ~[**ɛ**k]



e. [cygida]~ [cyk]



f. [nøgida]~[nøk]

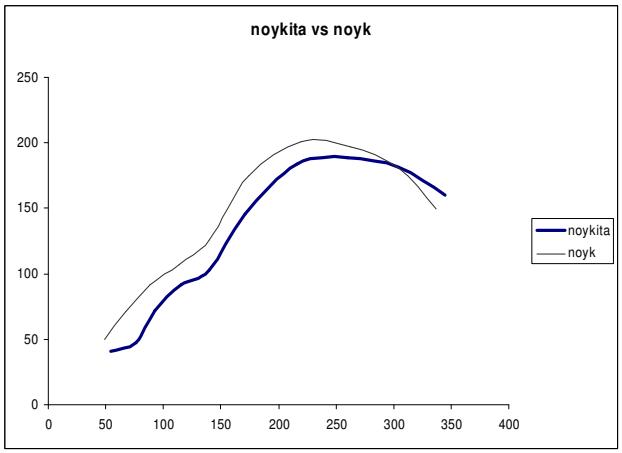


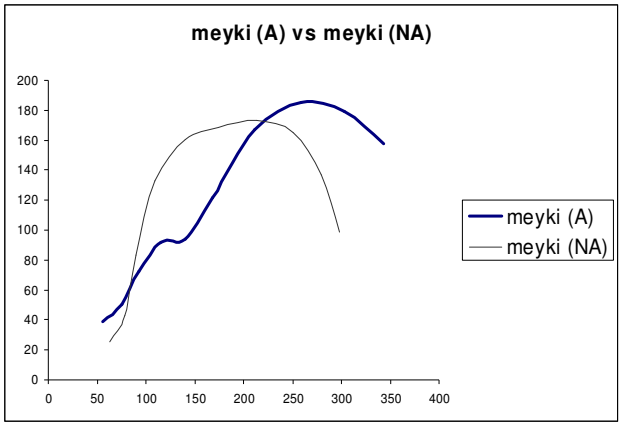
Fig. 4. Tongue body shapes of front vowels in assimilated forms (darker lines) and corresponding front vowels in control words (lighter lines) of K1 speaker.

In summary, overall this ultrasound imaging results reveal that /i/ vowel regressive assimilation is implemented truly categorically, but not gradiently. Thus, this finding confirms "phonological status" hypothesis, shedding light on the usefulness of ultrasound imaging to test the status of phonological rules in terms of articulation.

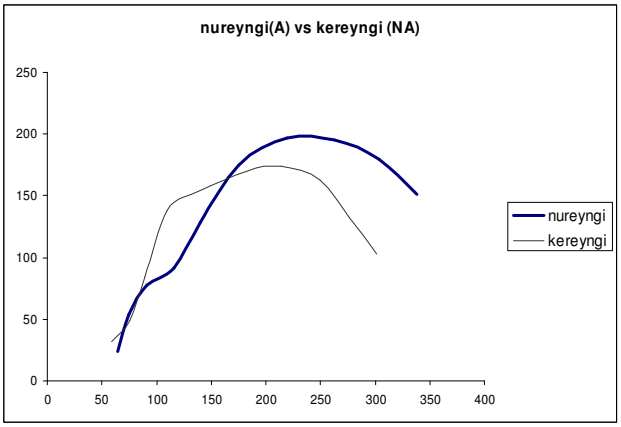
4.4 "Phonological enhancement" hypothesis

Fig. 5 displays the comparative tongue body positions of the front vowels in assimilated words (darker lines) and of the same front vowels in unassimilated words (lighter lines). On the basic reasoning that the application of assimilation rules directly facilitates the implementation of low-level coarticulation patterns, we expected that the front vowels which undergo assimilation would be articulated more forward than the same front vowels which do not. The factors of sex, dialects, and individual variation were not considered because of the difficulty of accessing statistical analysis. The correlation of the vowel height with the degree of coarticulation was also exempt from consideration.

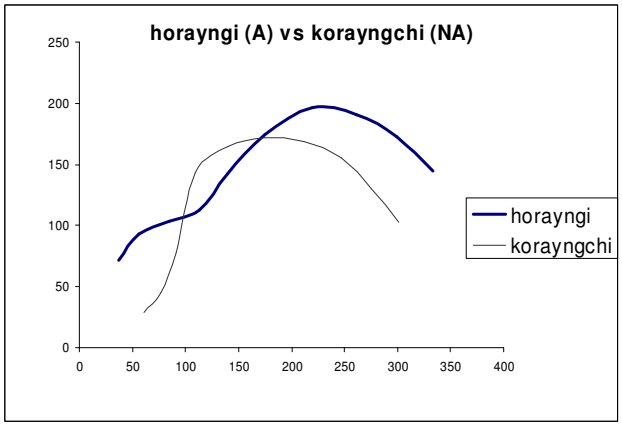
a. [m**e**gi]~[m**e**gi]



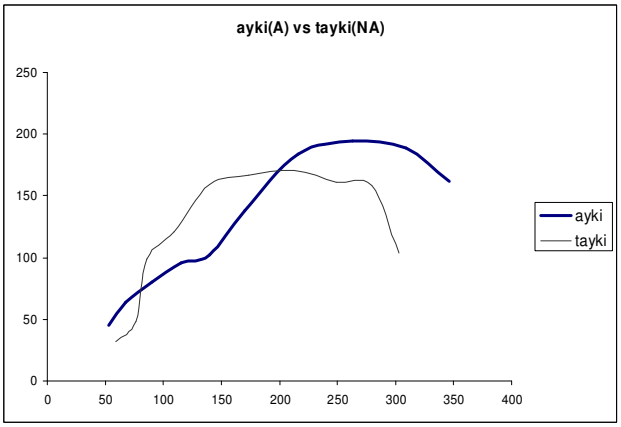
b. [nur**e**ŋi]~[kər**e**ŋi]



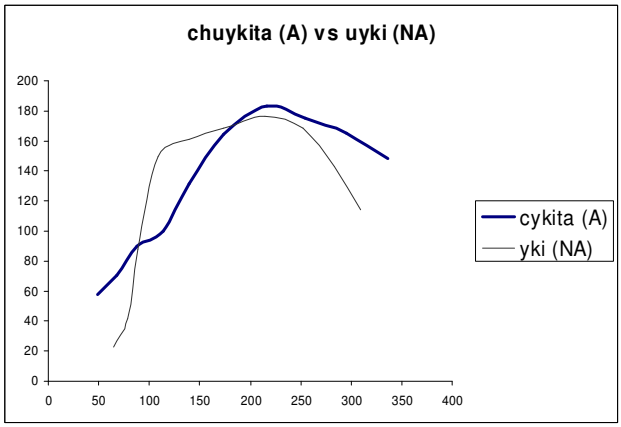
c. [hor**ɛ**ŋi]~[kor**ɛ**ŋci]



d. [**ɛ**gi]~[t**ɛ**gi]



e. [c**y**gida]~[**y**ki]



f. [n**ø**gida]~[▶▶▶▶▶▶⧗]

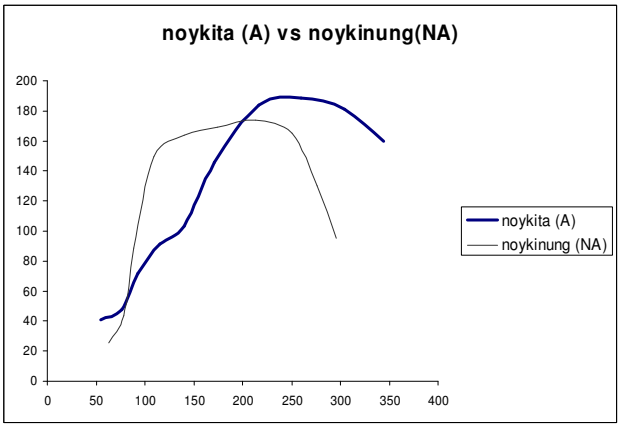


Fig. 5. Tongue body shapes of front vowels in assimilated forms (darker lines) and corresponding front vowels in nonassimilated control words (lighter line) of K1 speaker.

First, interestingly, we found that the front vowels in assimilated words were articulated considerably forward than the same front vowels in unassimilated words as illustrated in the 6 pairs of words in Fig. 5. Although actual phonological strings (i.e. VCV) are the same both in assimilated words and unassimilated words, the degree of coarticulation was found to be stronger in case of phonological rule environments than in case of unassimilated words. These results confirm "phonological enhancement of coarticulation" hypothesis, i.e. that the application of assimilation rules directly affect the more exertion of anticipatory V-to-V coarticulation. Overall the other two speakers showed the similar patterns as K 1 speaker. One speaker exhibited the opposite patterns for two word pairs such as /nuleyngi/ vs /keleyngi/ and /holayngi/ vs /kolayngchi/. That is, the front vowels in nonassimilated words were articulated more forward than those in assimilated words. At this point, we do not yet give some proper accounts for these patterns. It might be due either to some lexical frequency effects or to the confusion of actual pronunciation for the very approximate distance of two vowels in /e/ and /ɛ/ in the vowel space in Korean.

Second, some might consider the possibility that the difference of degree of V-to-V coarticulation lies in the degree of lexical cohesion among the segments within the relevant words. That is, since the VCV sequence within unassimilated words is more strongly stored in the mental lexicon than the same sequence within assimilated words, V-to-V coarticulation might be expected to be more prominent in unassimilated words. This expectation is entirely in disagreement with the results of our experiments here. Given that line of reasoning, we rather suggest that the actual coherence of VCV sequence in mental lexicon is loose until the sequence is actually pronounced along with the online implementation of phonological rules. More detailed implications on the interaction between phonological rules and coarticulation will be discussed in the following section.

5. Discussions

This study investigated the V-to-V coarticulation patterns especially involving the environment of /i/ vowel regressive assimilation rule in Korean. We focused on 4 hypotheses on the directionality of coarticulation, phonological status of the assimilation rule and phonological enhancement of coarticulation.

First, as for directionality of coarticulation, results based on production of VCV sequences by 3 native speakers of Korean, confirmed hypothesis (1) and (2), revealing the expected anticipation effects. As degree of articulatory constraint (DAC) expects, the test results on H (1) and H (2) showed anticipation over carryover effects. It is because this particular i-vowel regressive assimilation rule

environment involves the most coarticulation-resistant (i.e.insensitive) front vowel /i/ and velars (Recasens 1990; Recasens and Romero 1997; Recasens et al 1997). The results also confirm Recasens (1999) that dorsal consonants allow transconsonantal coarticulation as for [k] even though less. However, Recasens mentions that vowel-dependent carryover effects have been reported to exceed vowel-dependent anticipatory effect across dorsal consonants. Unlike that trend, however, vocalic anticipation in VCV sequences in Korean is found to exceed vocalic carryover in this study. If so, a naturally arising question is whether the directionality of V-to-V coarticulation is language particular or not irregardless of the degree of articulatory constraints of the intervening consonants. There has been relatively rich amount of research on English. For example, English is reported to show anticipatory V-to-V coarticulation rather than carryover effects (Clark & Sharf 1973; Fowler & Smith 1986; Öhman 1966; Kent 1972; Kent & Moll 1972; Ladefoged). On the other hand, production data in English show that carry-over effects generally exceed anticipatory effects in physiological (Gay 1974; Parush, Ostry & Munhall 1983) and acoustic data (Bell-Berti & Harris 1976; Fowler 1981a; Huffman 1986). Taking the previous discussions together, some argue that carryover effects are phonetically widespread and general phenomena, but anticipatory effects require programming. But our results in Korean imply that the directionality of coarticulation in a sequence of VCi may be expected purely on the prediction of DAC. Of course, this expectation does not exclude the possibility that V-to-V anticipatory effects here cannot be preprogrammed at high-level cognitive domain. So we have two lines of explanations; (i) directionality of coarticulation in Korean can be sufficiently expected purely in the component of language-particular phonetic implementation, or (ii) anticipation effects here could be preprogrammed in phonological grammar because of the opposite trend to the general patterns in other languages like English. This issue might not be definitely determined at present but the consideration of the "phonological enhancement of coarticulation" hypothesis may shed light on this matter, which will be dealt with in the below.

Second, the finding that anticipatory coarticulation occurs in the particular phonological environment whether it is purely phonetic or phonological confirms the assumption that V-to-V coarticulation occurs irrespective of the number of intervening consonants (Öhman 1966; Perkell, 1969; Fowler 1981a). Öhman suggested that vowels are coproduced with their neighboring consonants, and the production of a consonant is seen as a gesture superimposed on a continuous diphthongal vowel gestures. That is, as Fowler and Brancazio (2000) mentioned, "…in a plan to produce a VCV, speakers plan to begin producing V2 during V1…". We think the basic reason of vowel stream production may be in some

extent related to articulatory factor. The production of vowels involves slow and steady movements of jaws, while the articulation of most of the consonants resorts to relatively fast lingual movement.

Third, the results on H (3) in 4.3 showed that the assimilated front vowels are almost the same as the isolation vowels in terms of tongue body position. This indicates that i-vowel assimilation rule is truly phonological (i.e. change the feature from [+back] to [−back]. On the basis of this study, we suggest that articulatory study is a useful tool to see if assimilation and coarticulation lie in the continuum along the tongue body position. Much of coarticulation research relied on F1/F2 measurements, which indirectly reflect the vowel height and backness. But that approach still reveals some limitation in that it is not clear how to interpret or relate acoustic measures to articulatory tongue positions.

Lastly, one of the striking findings on H (4) is that assimilation enhances the degree of coarticulation. That is, although actual phonological strings (i.e. VCV) are the same both in assimilated words and unassimilated words in the output, the degree of coarticulation was found to be stronger in case of phonological rule environments than in case of unassimilated words. This finding implies that high level phonology might directly interact with low level phonetics. Barry (1992) also mentions "the implication that low-level phonetic variation may not all be accounted for "free of charge" by phonetic implementation and that instead the domain of phonology may need to set its bounds much closer to the fine detail of articulatory activity than has generally been acknowledged". As mentioned above with regard to the directionality of coarticulation in Korean, the directionality on coarticulation in this study, which is different from Recasens might be another evidence that "microscopic" phonetic variation also be incorporated into "macroscopic" phonological knowledge, not in the "purely the result of vocal tract constraints" (Ohala, 1992). Following Barry (1992), Flemming (2001), Gafos (2002), I take a unified model of phonetic-phonology on the basis of interaction between high-level phonological rules and low-level coarticulation. Specifically they claim that temporal relation of gestures must be included in formal grammar and that constraints on gestures involving coarticulation directly interact with the constraints on phonological assimilation. That is, phonological grammar I follow here consists of (traditional) phonological features, gestures of each segment and constraints which deal with the dynamic relations of gestures such as overlapping and weakening. Of course, we need to look into more articulatory and acoustic data revealing the interaction between phonological rules and coarticulation cross-linguistically. So our suggestion awaits further confirming data and is still programmatic. Nevertheless, it is worthwhile to attempt a formal analysis to incorporate low-level phonetic detail into a cognitive phonological grammar at

least in Korean. For example, it might be possible to consider the following constraints and their ranking in Korean; (i) IDENT (target) : The gestural target of an input segment must be preserved in its output correspondent. (ii) V1-to-V2 : The release of the V1 gesture must be synchronous with the onset of the V2 gesture ; (iii) V2-to-V1 : The target of V2 gesture must be synchronous with the onset of the V1 gesture.: (iv) Palatalization, V2-to-V1 >> IDENT (target) >> V1-to-V2. The attempts to integrate phonological rules with phonetic rules are not novel, but have been made in phonological traditions such as lexical phonology and standard optimality theory with rules and constraints.

6. Conclusions

In this ultrasound study, we explored the coarticulatory patterns in a VCV sequence involving vowel assimilation rule in Korean. Measures of tongue body positions from 3 Korean speakers were obtained. In unassimilated forms, anticipatory coarticulation effects were shown over carryover effects. Results of assimilated forms showed that assimilation rules are truly phonological and that the assimilated front vowels undergo stronger anticipatory effects than the same vowels in nonassimilated forms. Consideration of both unique V-to-V anticipation effects and phonological enhancement of coarticulation supports a unified model of phonetics-phonology. Further, these findings are consistent with both the notion of degree of articulatory constraints and the view that consonants and vocalic gestures in VCV sequences are ruled by relatively independent articulatory subsystems. Of noted contribution is that this study is the first systematic revelation on the direct effects of high-level phonological rules on low-level coarticulation.

Nonetheless, further studies are still worth pursuing to investigate more cross-linguistic coarticulatory patterns with respect to phonological rules. Does the degree of coarticulation differ between assimilable words and non-assimilable words as Recasens et al.'s (1997) prospect that phonetic segments more prone to undergo assimilation exhibit prominent coarticulatory effects along the relevant ariculatory dimensions? Does the degree of coarticulation differ according to the intervening consonants? What about the convincing relation between F1/F2 coarticulation patterns and articulatory coarticulation? These questions await further investigation of more articulatory and acoustic experiments.

References

Barry, M. 1992. Palatalization, assimilation and gestural weakening in connected speech, *Speech Communication*, 11: 393-400.

Bell-Berti, F. & Harris, K. S. 1976. Some aspects of coarticulation, *Haskins Laboratories Status Report on Speech Research*. SR45/46. 197-204.

Clark, M. & Sharf, D. J. 1973. Coarticulation effects of post-consonantal vowels on the short-term recall of pre-consonantal vowels, *Language and Speech*, 16: 67-76.

Edwards, J., Beckman, M. E. & Fletcher, J. 1991. The articulatory kinematics of final lengthening, *Journal of the Acoustical Society of America*, 89: 369-382.

Flemming, E. 2001. Scalar and categorical phenomena in a unified model of phonetics and phonology. *Phonology* 18: 7-44.

Fowler, C. A. 1981. A relationship between coarticulation and compensatory lengthening, *Phonetica*, 38: 35-50.

Fowler, C. A. & Brancazio L. 2000. Coarticulation Resistance of American English Consonants and its Effects on Transconsonantal Vowel-to-Vowel Coarticulation. *Language and Speech*, 43(1): 1-41.

Fowler, C. A. & Smith M. 1986. Speech perception as 'vector analysis': An approach to the problem of segmentation and invariance, In *Invariance and variability of speech processes* (J. S. Perkell & D. H. Klatt, editors), pp. 123-136. Hillsdale, NJ: Erlbaum.

Gafos, A. I. 2002. A grammar of gestural coordination. *Natural Language & Linguistic Theory* 20: 269-337.

Gay, T. 1974 A cinefluorographic study of vowel production, Journal of Phonetics, 2: 255-266.

Hardcastle, Williams & Nigel Hewlett. 1999. *Coarticulation: Theory, Data and Techniques*. Cambridge: Cambridge University Press.

Huffman, Ml. K. 1986. Patterns of coarticulation in English, *UCLA Working Papers in Phonetics*, 63: 26-47.

Ohala, J. 1992. "Comments on Nolan's 'The descriptive role of segments: evidence from assimilation'", in *Papers in Laboratory Phonology II*, ed. By D. R. Ladd and G. J. Docherty (Cambridge Univ.Press, Cambridge).

Öhman, S. E. G. 1966. Coarticulation in VCV sequences: Spectrographic measurements. *Journal of the Acoustical Society of America*, 39: 151-168.

Parush, A., Ostry, D. J. & Munhall, K. 1983. A kinematic study of lingual coarticulation in VCV sequences, *Journal of the Acoustical Society of America*, 74: 1115-1123.

Perkell, J. S. 1969. *Physiology of speech production: Results and implications of a quantitative cineradiographic study* Cambridge, MA: MIT Press.

Recasens, Daniel. 1990. "The articulatory characteristics of palatal consonants," J. Phonetics 18: 267-280.

Recasens, Daniel. 1999. Lingual coarticulation. In *Coarticulation: Theory, Data and Techinques*. (ed) by Hardcastle & Hewlett. Cambridge: Cambridge University Press.

Recasens, D., Pallarès, M. D., and Fontdevila, J. 1997. A model of lingual coarticulation based on articulatory constraints. *Journal of the Acoustical Society of America* 102: 544-561.

Recasens, D. and Romero, J. 1997. "An EMMA study of segmental complexity and articulatory-acoustic correlations for consonants," Eur.J. Disorders Commun. 30: 203-212.

Sohn, H. M. 1999. *The Korean language*. Cambridge, U.K.; New York : Cambridge University Press.

Gwanhi Yun
Depts. of Linguistics
University of Arizona
Douglass Building, Room 200-E
PO Box 210028
Tucson, AZ 85721
ghy@u.arizona.edu