말소리와 음성과학 제5권 제1호 (2013. 3. 31)
ISSN 2005-8063, pp. 109~121

Articulatory Attributes in Korean Nonassimilating Contexts

Son, Minjung[1]

ABSTRACT

This study examined several kinematic properties of the primary articulator (the tongue dorsum) and the supplementary articulator (the jaw) in the articulation of the voiceless velar stop (/k/) within nonassimilating contexts. We examined in particular the spatiotemporal properties (constriction duration and constriction maxima) from the constriction onset to the constriction offset by analyzing a velar (/k/) followed by the coronal fricative (/s/), the coronal stop (/t/), and the labial (/p/) in across-word boundary conditions (/k#s/, /k#t/, and /k#p/). Along with these measurements, we investigated intergestural temporal coordination between C1 and C2 and the jaw articulator in relation to its coordination with the articulation of consonant sequences. The articulatory movement data was collected by means of electromagnetic midsagittal articulometry (EMMA). Four native speakers of Seoul Korean participated in the laboratory experiment. The results showed several characteristics. First, a velar (/k/) in C1 was not categorically reduced. Constriction duration and constriction degree of the velar (/k/) were similar within nonassimilating contexts (/**k**#s/=/**k**#t/=/**k**#p/). This might mean that spatiotemporal attributes during constriction duration were stable and consistent across different contexts, which might be subsequently associated with the nontarget status of the velar in place assimilation. Second, the gestural overlap could be represented as the order of /k#s/ (less) < /k#p/ (intermediate) < /k#t/ (more) as we measured the onset-to-onset lag (a longer lag indicated shorter gestural overlap.). This indicates a gestural overlap within nonassimilating contexts may not be constrained by any of the several constraints including the perceptual recoverability constraint (e.g., more overlap in Front-to-Back sequences compared to the reverse order (Back-to-Front) since perceptual cues in C1 can be recovered anytime during C2 articulation), the low-level speech motor constraint (e.g., more overlap in lingual-nonlingual sequences as compared to the lingual-lingual sequences), or phonological contexts effects (e.g., similarity in gestural overlap within nonassimilating contexts). As one possible account for more overlap in /k#t/ sequences as compared to /k#p/, we suspect speakers' knowledge may be receptive to extreme encroachment on C1 by the gestural overlap of the coronal in C2 since it does not obscure the perceptual cue of C1 as much as the labial in C2. Third, actual jaw position during C2 was higher in coronals (/s/, /t/) than in the labial (/p/). However, within the coronals, there was no manner-dependent jaw height difference in C2 (/s/=/t/). Vertical jaw position of C1 and C2 was seen as inter-dependent as higher jaw position in C1 was closely associated with C2. Lastly, a greater gap in jaw height was associated with longer intergestural timing (e.g., less overlap), but was confined to the cluster type (/kp/) with the lingual-nonlingual sequence. This study showed that Korean jaw articulation was independent from coordinating primary articulators in gestural overlap in some cluster types (/k#s/, /k#t/) while not in others (e.g., /k#p/). Overall, the results coherently indicate the velar stop (/k/) in C1 was robust in articulation, which may have subsequently contributed to the nontarget status of the velar (/k/) in place assimilation processes.

Keywords: gestural overlap, jaw, nonassimilating, nontarget, velar

1. Introduction

In consecutive stop-stop sequences, coronal stops are more likely to be assimilated to the following consonant (labial or velar) (Paradis & Prunet, 1991). This is true cross-linguistically as well as language-internally. In a typological study of place assimilation in seventeen languages (Jun, 1995), all demonstrated the targeting of coronals (e.g., Catalan, English, German, Toba Batak, Yokut, etc.), fewer languages for the targeting of labials (eight languages, including Korean, Hindi,

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[1] Hannam University, minjungson@hnu.kr

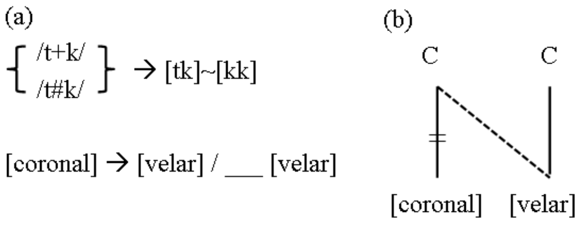
Received: February 6, 2013
Revised: March 11, 2013
Accepted: March 14, 2013

etc.) and dorsals (five languages, including Diola Fogny, Japanese, etc.). To quote Jun's (1995: 71) implicational statements, "if velars are targets of place assimilation, so are labials; if labials are targets of place assimilation, so are coronals." Byrd (1996) suggested that coronals were weaker such that they were more agile, which could have subsequently led to shorter formant transition cues, and in turn, less robust perceptual cues as compared to labials or dorsals. By contrast, velars, which are the least likely to become targets of place assimilation, carry robust acoustic cues known as *velar compactness/pinch* (i.e., convergence of F2 and F3 in the formant transitions of the adjacent vowel) (Jakobson, Fant, & Halle, 1968). This is also true regardless of manner of articulation (e.g., stop or fricative) in C2.

Korean place assimilation, known to be optional and rate-dependent in its occurrence, was traditionally accounted for in Generative Phonology (Chomsky & Halle, 1968). In particular, the rule-based phonology using rewrite rules proposed that place assimilation (e.g., /tk/→[tk]/[kk]) occurred as a result of the application of place assimilation as in (1a). Likewise, Autosegmental Phonology within the tradition of classical Generative Phonology proposed a series of processes on the autosegmental representation: a delinking process (=) is followed by a reassociation process (dotted line) as shown in (1b) (Clements, 1985; Cho, 1990). As shown in the analyses in (1), the relevant features for [PLACE] were formally stated with a set of other features.

(1) Place assimilation rule

(Slightly modified from Kim-Renaud (1974) and Cho (1990): In (a), the symbols "+" and "#" indicate a morpheme boundary and a word boundary, respectively.)



Under the representational systems in classical Generative Phonology, the phonetic representation served as the input of a universal implementation rule, through which physical outputs are ultimately spit out (Chomsky & Halle, 1968). The theory of underspecification in the tradition of Generative Phonology later proposed that place assimilation targeted coronals most frequently since the place feature for a coronal was empty in the underlying representation and later filled in (McCarthy & Taub, 1991; Steriade, 1995). However, even coronal underspecification was not sufficient to justify why labials also become targets of place assimilation, but not velars.

The other limitation of traditional Generative Phonology is that the theory is not appropriate for accommodating physiological or perceptual constraints on gestural overlap with respect to different implicational statements about triggers. To quote Jun (1995:79), "If coronals are triggers [of place assimilation], so are velars." For example, if there is a coronal in C1, a labial or a velar in C2 can be a trigger. If there is a labial in C1, only a velar in C2 can be a trigger. Recently, articulatory studies on place assimilating languages have also improved our understanding in research on variability in the articulation of consonants from various languages such as American English, British English, German, Georgian, Korean, Russian, Spanish, Swedish (Browman & Goldstein, 1990, 1991; Chitoran, Goldstein, & Byrd, 1992; Jun, 1995, 1996, 2004; Honorof, 1999; Kühnert, Hoole, & Mooshammer, 2006; Kochetov & Pouplier, 2008; Son, Kochetov, & Pouplier, 2007; Kochetov, Pouplier, & Son, 2007; Son, 2008a, 2008b, 2011a, 2011b). In particular, results from articulatory studies have shown that place assimilation occurred to some extent either as gestural overlap between the target and the trigger, spatiotemporal reduction of the target stop, or both (Jun, 1995, 1996, 2004; Nolan, 1992; Kühnert & Hoole, 2004; Son et al., 2007; Kochetov & Pouplier, 2008; Son, 2008b among others). Perceptual recoverability subsequently varied with different degrees of gestural overlap and gestural reduction within assimilating contexts (Jun, 1995; Byrd, 1996; Chen, 2003; Son et al., 2007 among others). Likewise, it is also conceivable that the strong status of velars (e.g., /k/, /g/, and /ŋ/) can be, to some extent, equally accounted for under the same premises of Articulatory Phonology (i.e., gestural overlap and gestural reduction).

In American English, comparing /d#g/ (e.g., 'type ba**d** **g**ab again.') with the reverse order /g#d/ (e.g., 'type ba**g** **d**ab again.'), the assimilating sequence /d#g/ showed longer sequence duration and more sequence overlap (Byrd, 1996). That is, a word-initial tongue dorsum constriction gesture substantially impeded a word-final tongue tip constriction gesture, but not vice versa. Consequently, the word-final coronal stop is assimilated to the following consonant while the opposite ordering resists such a phonological process. With respect to gestural reduction, note that reduction frequency varied either as a function of the *target* place or the *trigger* place in Korean, showing that it was lower for a labial followed by a velar (/**p**+k/, /**p**#k/), intermediate for a coronal followed by a velar (/**t**+k/, /**t**#k/), and higher for a coronal followed by a labial (/**t**+p/, /**t**#p/). In this regard, velars (/k/, /g/) showed less gestural overlap, together with near absence of gestural reduction (cf., few occurrences of partial reduction in /k/) (Kochetov & Pouplier, 2008).

Although nonassimilating C1C2 clusters with a velar stop (/g/) in C1 exhibited less overlap as compared to assimilating sequences with a target coronal (/d/) from Byrd (1996), there was still some variation in gestural overlap with a velar (/g/) within nonassimilating contexts. In response to variations in manner of articulation in C2, the onset-to-onset lag in /g#s/ sequences ('Say ba**g** **s**ab.') was shorter (i.e., more overlapped) than that in nonassimilating /g#d/ sequences ('Say ba**g** **d**ab.') (/g#s/>/g#d/) (Byrd & Tan, 1996).

A possible motive for the difference in degree of gestural overlap within nonassimilating contexts in Byrd and Tan (1996), cited above (/g#s/>/g#d/), may find a basis for different jaw height. Variability in gestural overlap within nonassimilating contexts in C1 was also attested in a cross-linguistic study on a nontarget labial (/p/) in English and Taiwanese (Gao, Mooshammer, Hagedorn, Nam, Tiede, Chang, Hsieh, and Goldstein, 2011). Nonassimilating /p#t/ sequences in Taiwanese exhibited more overlap, with a synchronous coordination between C1 and C2, than nonassimilating /p#k/ sequences (/p#t/>/p#k/). Gao et al. (2011) attributed different intergestural timing patterns between these sequences to different jaw height in C2. The jaw articulator is known as a *shared* articulator (Browman & Goldstein, 1991) and vertical jaw position was in the order of coronal-labial-velar, from higher to lower, in English and Swedish (Browman, 1994; Keating, Lindblom, Lubker, & Kreiman, 1994). Accordingly, vertical jaw position in C1 of /**p**#t/ sequences in Taiwanese was *a priori* suspected to be higher as compared to that of /**p**#k/, the former temporally showing a synchronous coordination (/p#t/>/p#k/). To quote Gao et al. (2011:726), "Because the formation of both [p] and [t] constriction involves the jaw movement, a possible explanation is that it is more natural and more *economic* to articulate [p] and [t] in a near-synchronous manner." Therefore, given that coronals were more distinct in the order fricative-stop depending on manner of articulation (Mooshmmer, Hoole, & Geumann, 2007), the motive for distinct gestural overlap patterns between /g#s/ and /g#d/ could be found in the active role of jaw height such that the English fricative-stop contrast alluded to the same low-level physical constraint on jaw height (/g#s/>/g#d/).

However, the *low-level speech motor constraint* on jaw height was not able to account for the difference in different sequence types within English in a consistent way. When compared to Taiwanese (/p#t/>/p#k/), English did not necessarily show more overlap in /p#t/ sequences (/p#t/</p#k/). Another divergent pattern was observed in Korean. When compared to English (/g#s/>/g#d/), Korean showed, by contrast, less overlap in within-word /k+s/ sequences (/ʧiha**ks**a/ 'Jihak company') as compared to /k+t/ sequences (əha**kt**ap/ 'responses in the verbal section') (/k+s/</k+t/). Based on the results of cross-linguistic articulatory studies, it seems that the low-level physiology based on jaw height is selectively active.

In this study, we examine whether and, if so, how robust articulatory cues of a velar (/k/) are and also gestural overlap of C1C2 sequences within nonassimilating contexts in order to find hints as to why a velar (/k/) is less likely to become a *target* of place assimilation while a coronal (/t/) is less likely to become a *trigger*. In order to test the strong resistance of velars as targets and the weak status of coronals as triggers of place assimilation, we navigate spatiotemporal dimensions of oral articulators to reveal that i) a velar (/k/) in C1 demonstrates in general robust articulatory cues in the supralaryngeal level of speech (e.g., no segmental deletion, less variability in time and space across different contexts, etc.), and ii) a coronal (/t/) demonstrates some temporal attributes - in particular, we will examine the relative timing of a coronal (/t/) with respect to a preceding velar (/k/) in comparison with a labial (/p/).

Equally importantly, since the low-level physical constraint on the jaw does not seem to be consistently related to gestural overlap either cross-linguistically or within-language across the board, we examine the role of the supplementary jaw articulator as far as its coordination with primary articulators in Korean C1C2 sequences. In this paper, we examine a velar (/k/) within nonassimilating contexts, with manipulated places of articulation and manners of articulation in C2. In order to make syntactic conditions between English and Korean comparable, we use three nonassimilating contexts in across-word condition (/k#s/, /k#t/, and /k#p/). We are interested in the following four research queries to further this line of research.

1.1 Research questions

First, we examine constriction duration and constriction degree of the tongue dorsum gesture for a velar (/k/) in three across-word nonassimilating contexts (/k#s/, /k#t/, and /k#p/). Previous articulatory studies on place assimilation (Kochetov & Pouplier, 2008) showed that the reduction of a labial (/p/) was sensitive to phonological context effects, with reduction confined to assimilating contexts (/pk/) (41 out of 133 tokens (approx. 31% of occurrences)). Within assimilating contexts, a coronal (/t/) was also reduced in time and space (116 out of 204 tokens (approx. 57% of occurrences)), with more frequent reduction in /tp/ sequences as compared to /tk/. Although a velar is not normally known as the target of place assimilation for Korean, there is some evidence of spatiotemporal reduction of a velar (/k/). There were few instances of gradient reduction of a velar (/k/), although it was very limited in the number of occurrences by only one out of three speakers (7 out of approx. 208 tokens (approx. 3% of occurrences)). We will therefore proceed to test a query about whether a velar (/k/) within nonassimilating contexts generally exhibits reduction in time and space in various additional segmental contexts.

Secondly, gestural overlap is known to be an inducing factor for place assimilation. Consonantal sequences with more gestural overlap are closely related to assimilated perceptual responses (e.g., /pk/→[kk] from Son et al. (2007)). However, gestural overlap-driven perceptual assimilation was sensitive to the place of oral articulators in C1. In a forced-choice identification task, American-English listeners rendered assimilated responses after hearing synthesized stimuli with various degrees of gestural overlap when a coronal (/d/) was followed by a labial (/b/) (/d#b/→[bb]). However, even extreme degrees of gestural overlap in the reverse order (/b#d/) did not cause assimilated responses - a labial (/b/) remained unassimilated (/b#d/→[bd], *[dd]) (Byrd, 1992). If we interpret Byrd's (1992) results in view of the different natures of triggers between a labial and a coronal, increased overlap from a labial could jeopardize the recovery of C1, but not overlap from a coronal. Extending this idea to nonassimilating contexts with a velar (/k/) in C1, we are interested to know in learning whether and, if so, how gestural overlap within nonassimilating contexts differs as a function of the place of articulation in C2. Our preliminary hypothesis is that a potential trigger (labial in this case) may show less overlap with the preceding consonant while a nontrigger (coronal in this case) may show more overlap.

Thirdly, we examine vertical jaw position in both C1 and in C2. Previous research on cross-linguistic study on gestural overlap did not directly measure actual jaw position in heterorganic C1C2 sequences (e.g., Gao, et al., 2011). In this paper, we measure vertical jaw movement trajectory in C1 as well as C2 within nonassimilating heterorganic sequences and test the validity of the *speech motor* constraint-based hypothesis working together with gestural overlap between primary articulators. Although jaw height difference was manifested in the order of coronal fricative (/s/) - coronal stop (/t/) - labial stop (/p/) - velar stop (/k/), from higher to lower (e.g., German from Mooshammer et al. (2006)), Korean has not been systematically investigated in this regard. We proceed this line of inquiry as we examine whether and, if so, i) how jaw height in C2 (/s/, /t/, /p/) differs, and ii) how the jaw height in a velar (/k/) in C1 varies as a function of different jaw height in C2. Along with the issue of a possible influence of jaw height in C2 on that of C1, we examine whether motives for gestural overlap can be attributed to the jaw, supplementary articulator. As suggested in Gao et al. (2011), we are particularly interested in learning the relationship between the difference in gaps of jaw height which spanned C1C2 sequences. Although Korean exhibited language-specific gestural overlap in velar-coronal sequences (/k+s/</k+t/ in the word-internal condition from Son (2011)) as compared to English (/g#s/>/g#d/ in the across-word boundary condition from Byrd and Tan (1996)), we extend the scope of study on gestural overlap in velar-coronal sequences to the across-word boundary condition to discover whether language-specific intergestural timing is manifested in Korean or if any similarity in gestural overlap is attested in both languages.

2. Method

We used an Electromagnetic Midsagittal Articulometer (EMMA) system that was devised at the Massachusetts Institute of Technology (MIT) (Perkell, Cohen, Svirsky, Matthies, Garabieta, & Jackson, 1992). The device is a two-dimensional system that concurrently records movement trajectory data of the lips, the tongue tip, the tongue dorsum, and the jaw. It has a built-in three-coil transmitter assembly in a plastic head helmet, two on the sides and one on the rear (the left panel of Figure 1).

A total of seven pellets were used to collect articulator movement data. The size of each pellet was approximately 1.5 × 1.5 × 1.0 mm. Four pellets were glued on the tongue from the tongue dorsum to the tongue tip with roughly equal distances. One pellet was glued on the lower incisor to collect jaw movement data. Two more pellets were glued on the upper and lower lips while the lips were naturally closed. Two more pellets were used to correct any unintentional head movement during speech: one was glued on the upper incisor and the other on the nose ridge (the right panel of Figure 1).

To estimate the actual positions of articulators such as the tongue tip, the tongue body, the lips, and the jaw, the occlusal plane passing through the biting surfaces of the teeth was acquired from two pellets attached to a plastic bite plate, which was approximately 5.5 × 5.0 mm in size. Articulatory data were sampled at 200 *Hz* (that is, articulatory movement of each pellet attached to the articulator was collected every 5 ms).

Taken together, the device provided the rectified output voltages which represent the location of each pellet (i.e., the distance of each pellet from each transmitter coil) every time a sample was taken. These corrected output voltages from raw movement data were subsequently converted to sample by sample positions in a Cartesian coordinate system, with the x-axis and the y-axis (Westbury, 1994; Son et al., 2007 among others). In order to extract articulator movement data for further analysis, we conducted post-processing procedures using the software Matlab 2008a by Mathworks. A low-pass filter of 20 *Hz* was used to smooth the kinematic data.

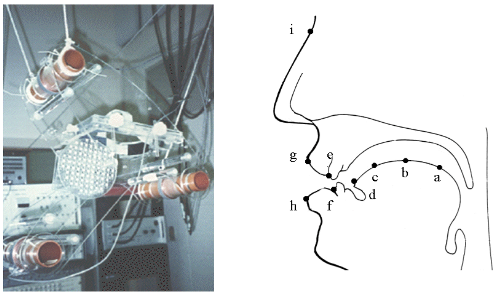


Figure 1. Locations of pellets: (a) the tongue dorsum; (b) the tongue body 2; (c) the tongue body 1; (d) the tongue tip; (e) the maxillary (upper) central incisors (as a reference point); (f) the mandibular (lower) central incisors (jaw height); (g)-(h) the upper and lower lips; and (i) the nose ridge (as a reference point).
(The left panel was adopted from the web site of Haskins Laboratories (www.haskins.yale.edu) and the right panel from Figure 1 in Son (2011a).)

2.1 Measurements

We analyzed the vertical tongue dorsum gesture for a velar (/k/), vertical tongue tip gesture for a coronal (/t/), and lip aperture (Euclidean distance between the pellets on the upper and lower lips) for a labial (/p/). In particular, LP-Findgest in MVIEW, which was developed at Haskins Laboratories (Tiede, 2005, a software program for articulatory data measurement (see Son et al., (2007); Kochetov & Pouplier (2008) among others) was used to demarcate six fundamental articulatory landmarks (gestural movement onset, peak velocity of closing movement, constriction onset, constriction offset, peak velocity of opening movement, gestural movement offset). The boundary of each event was marked out when the velocity of the corresponding articulator exceeded a threshold which referred to local speed minimum of each articulator movement and local speech maximum. We used 20% of the threshold during the analysis of data (For more details, see Son et al., 2007). LP-Snapex in MVIEW was used to demarcate constriction maxima. The vertical jaw position was also measured as we aligned the maximum constriction of each articulatory gesture. For further analysis, we made use of several relevant measurements (the closing/approximation onset, constriction duration (from the constriction onset to the constriction offset), and constriction maxima.

2.1.1 Kinematic measurements of tongue dorsum movement and tongue tip movement

The diagram shown in Figure 2 displays kinematic measurements of the tongue dorsum gesture of a velar (/k/) and the tongue tip gesture for coronals (/s/ and /t/). Also shown is the vertical jaw position which is aligned with the time point of the tongue dorsum constriction maxima (Figure 2d). Their detailed descriptions are also listed below.

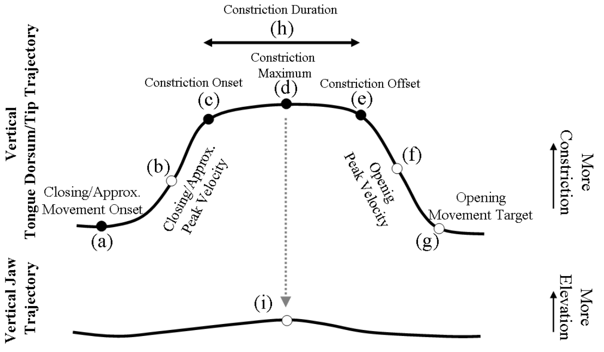


Figure 2. Schematized vertical tongue dorsum/tongue tip movement trajectory. The symbol " • " indicates relevant measurements used for further analysis.

(a) Closing movement onset (the tongue dorsum closing movement onset; the tongue tip closing/approximation movement onset) (Fig. 2a).

(b) Peak velocity (peak velocity of the tongue dorsum closing movement; peak velocity of the tongue tip closing/approximation movement (Fig. 2b).

(c) Constriction onset (constriction onset of the tongue dorsum movement; constriction onset of the tongue tip movement (Fig. 2c).

(d) Constriction maxima (constriction maxima of the tongue dorsum movement; constriction maxima of the tongue tip movement) (Fig. 2d).

(e) Constriction offset (constriction offset of the tongue dorsum movement; constriction offset of the tongue tip movement) (Fig. 2e).

(f) Peak velocity (peak velocity of the tongue dorsum opening movement; peak velocity of the tongue tip opening movement (Fig. 2f).

(g) Opening movement target (the tongue dorsum opening movement target; the tongue tip opening movement target) (Fig. 2g).

(h) Constriction duration (constriction duration of the tongue dorsum movement; constriction duration of the tongue tip movement) (Fig. 2h).

(i) Vertical jaw position (vertical jaw position aligned with the tongue dorsum constriction maxima; vertical jaw position aligned with the tongue tip constriction maxima (Fig. 2i).

2.1.2 Kinematic measurements of lip aperture

The diagram shown in Figure 3 displays kinematic measurements of the lip aperture gesture for a labial (/p/) and the vertical jaw position which is aligned with the time point of the lip aperture maxima (Figure 3d). Their detailed descriptions are also listed below.

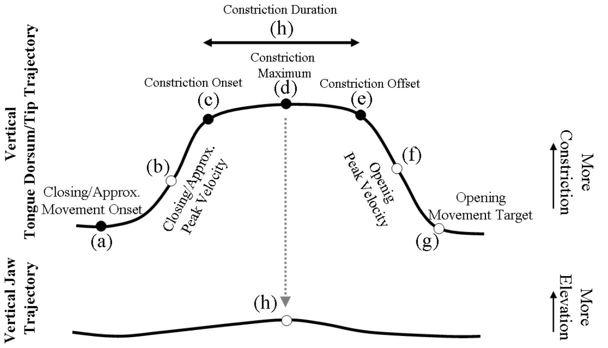


Figure 3. Schematized lip aperture movement trajectory. The symbol "•" indicates relevant measurements used for further analysis.

(a) Lip aperture closing movement onset (Fig. 3a).

(b) Peak velocity of lip aperture closing movement (Fig. 3b).

(c) Lip aperture constriction onset (Fig. 3c).

(d) Lip aperture constriction maxima (Fig. 3d).

(e) Lip aperture constriction offset (Fig. 3e).

(f) Peak velocity of lip aperture opening movement (Fig. 3f).

(g) Lip aperture opening movement target (Fig. 3g).

(h) Constriction duration of the lip aperture gesture (Fig. 3h).

(i) Vertical jaw position aligned with the lip aperture constriction maxima (Fig. 3i).

2.1.3 Gestural overlap between C1 and C2

As an index of intergestural overlap, we used the time interval between the constriction onset of C1 and that of C2 (onset-to-onset lag). Figure 4 shows only the relevant kinematic measurements for a sample velar-coronal sequence (The diagram is slightly modified from Son, 2011a).

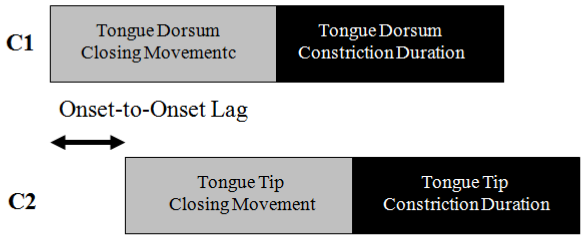


Figure 4. Schematized onset-to-onset lag as an indicator of gestural overlap in C1C2 (e.g. /k#t/).

2.2 Participants

Four native speakers of Seoul-Korean (one male and three female) took part in the EMMA experiment. At the time of the experiment, the participants were graduate students living in New Haven, CT (U.S.A). They were in their mid-twenties and early thirties, having spent their first twenty years in the Seoul or Kyung-gi-do area. None of them had speech or hearing problems. We did not inform the subjects of the purpose of experiment. Right before an EMMA session, each speaker was presented with speech materials prepared on paper so that s/he got familiarized with sentence structures as well as meaning.

2.3 Speech materials

We elicited three C1C2 sequences in the /a/-to/-/a/ context, which had a velar (/k/) as the first consonant. There was a word boundary between the first consonant and the second. The first stop consonant (/k/) is normally considered nonassimilating consonant sequences. Each consonant belonged to a real word.

We placed each phrase within a natural short sentence as shown in (2) below.

(2) Target C1C2 sequences
i. /tʃənha**k** **s**amohataka tʃənhakhessə/
'(I) transferred schools as I yearned to do (so).'
(전학 사모하다가 전학했어.)

ii. /əha**k** **t**aɨmɨlo suhaki muntʃeja/
'Next to (the) verbal (section), maths (section) is (a) big challenge (to me).'
(어학 다음으로 수학이 문제야.)

iii. /tʃənha**k** **p**attʃi anha/
'(We) do not get (a) transferred (student).'
(전학 받지 않아.)

Speakers were asked to read short natural sentences presented on a computer screen at comfortable speech rate (neither too fast nor too slow) in one session. The same materials were presented again to speakers to elicit fast speech rate. Speakers were asked to read each sentence four times in a row, placing a pause between utterances. A set of four repetitions of another sentence followed as fillers. Finally another group of repetitions was elicited. A total of 192 tokens were sent for further analysis (3 (Cluster type) × 2 (Speech rates) × 8 (Repetitions) × 4 (Speakers)).

2.4 Statistical analysis

We conducted reapeated measures analysis of variance (RM ANOVA), using SPSS (statistical product and service solutions) version 18. Only one piece of data per condition (i.e., the average of estimated values of each data point) was provided by each subject since the analysis used the subject as the experimental unit (Max & Onghena, 1999). Each articulatory gesture (i.e., the tongue dorsum gesture, the tongue tip gesture, the lip aperture gesture, and the jaw gesture) rendered a group of mean scores. We reported F-ratios, p-values, and Partial eta^2 (η^2) in RM ANOVAs, referring to Huynh-Feldt corrected degrees of freedom and error terms at $p<0.05$ (Huynh & Feldt, 1970). Post-hoc pairwise comparisons were carried out whenever the difference between levels within a factor with more than two levels needed to be determined, referring to least significance difference (LSD) at the significance level $p<0.05$. The possibility of close relationships between two independent variables were evaluated as we conducted Pearson product-moment correlation and linear regression coefficients at $p<0.05$. Independent samples t-tests were conducted adjunctly.

3. Results

3.1 Tongue dorsum constriction duration and constriction maxima

The results consistently demonstrated invariant spatiotemporal properties of a voiceless velar stop (/k/), which is exempt from being assimilated to the following stops in terms of place of articulation. Firstly, not a single token demonstrated categorical reduction (e.g., deletion). There was not a main effect of Cluster type on the constriction maxima of the tongue dorsum and on the constriction duration (/**k**#s/=/**k**#t/=/**k**#p/) (F[2,6]=1.56; F[1.7,5.2]=5, all at $p>0.05$) (Figures 5.a and 5.c). The similarity in the spatiotemporal properties of a velar (/k/) within the nonassimilating contexts might indicate that the nontargets of place assimilation are unchanging with no consequential obscuring of recoverability of C1. There was neigher a main effect of Speech rate on constriction degree of the tongue dorsum and on constriction duration (fast=comfortable) (F[1,3]=0.02; F[1,3]=2.45, all at $p>0.05$) (Figures 5.b and 5.d), nor a significant interaction between factors ($p>0.05$).

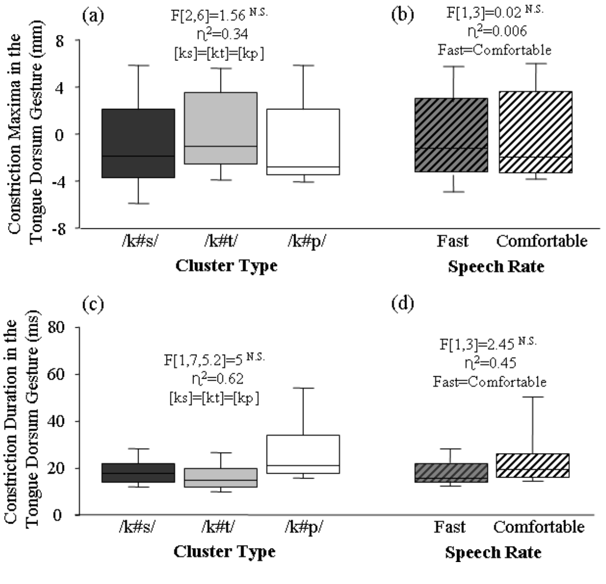


Figure 5. The constriction maxima in C1, /k/, as a function of (a) Cluster type effects and (b) Speech rate effects. ('=' refers to no statistical difference.)

3.2 Gestural overlap in C1C2 sequences

Longer onset-to-onset lag was observed in the order of /k#s/ (less overlap) - /k#p/ - /k#t/ (more overlap) (F[1.7,5.1]=28,

$p<0.005$) (Figure 6.a). This is compatible with Son's (2011) finding about longer lag in word-internal /k+s/ sequences (less overlap) in comparison with /k+t/ (cf., more overlap in /k#t/ sequences for English). However, there was not a main effect of Speech rate (F[1,3]=3.4, $p>0.05$) (Figure 6.b). Nor was there a significant interaction between factors ($p>0.05$).

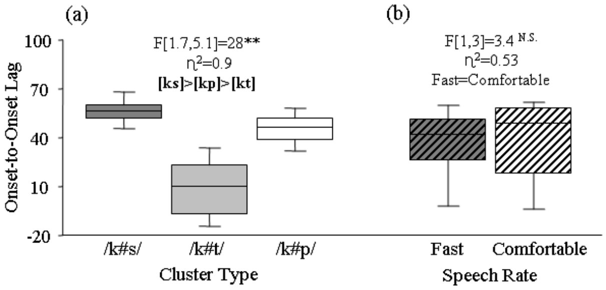


Figure 6. Onset-to-onset lag between C1 (/k/) and C2 (/s/, /t/, and /p/) as a function of (a) Cluster type and (b) Speech rate. ('**' refers to $p<0.005$; '>' denotes significant difference between levels and '=' no statistical difference.)

3.3 Vertical jaw position in C1C2 sequences

3.3.1 Vertical jaw position aligned with the maxima of the consonantal gesture in C2

Vertical jaw position was directly measured while it was aligned with the constriction maxima of consonantal gestures such as /s/, /t/, and /p/. There was a trend that the vertical jaw position was higher for the coronal fricative (/s/) in C2 as compared to the labial stop /p/ (/k#**s**/≥/k#**p**/). Likewise, we observed cluster type effects on the vertical jaw position, showing that the actual jaw height of a coronal stop (/t/) was greater than a labial (/p/) (/k#**t**/>/k#**p**/). However, vertical jaw height between a fricative (/s/) and a stop (/t/) within coronals was similar (/k#**s**/=/k#**t**/) (F[1.7,5]=7.53, $p<0.05$) (Figure 7.a). This indicates that Korean did not exhibit a manner-dependent difference in jaw height within coronals (cf., the different ranking for German with inter-speaker variability (/s/≥/t/) in Mooshammer et al., (2006)). There was neither a main effect of Speech rate on vertical jaw position (F[1,3]=4.6, $p<0.05$) (Figure 7.b), nor was there a significant interaction between factors ($p>0.05$).

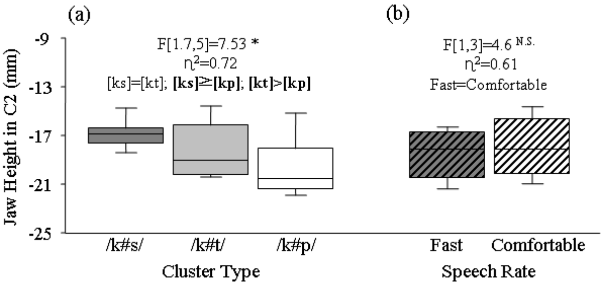


Figure 7. Jaw height in C2 (/s/, /t/, and /p/) as a function of (a) Cluster type and (b) Speech rate. ('*' refers to $p<0.05$; '>' denotes significant difference between levels and '=' no statistical difference.)

3.3.2 Jaw position aligned with tongue dorsum maxima in C1

The vertical jaw position of a velar (/k/) in C1 varied with different cluster types, being higher when it was followed by a coronal fricative (/s/) as compared to a labial (/p/) (/**k**#s/ > /**k**#p/) (F[2,6]=7.47, $p<0.05$) (Figure 8.a). However, the vertical jaw position of the voiceless velar stop followed by a coronal stop (/**k**#t/) was not distinguished from other sequence types (/**k**#s/=/**k**#t/; /**k**#t/=/**k**#p/). Although the spatiotemporal properties of the tongue dorsum gesture in a velar (/k/) were invariant across different segmental environments (as shown in Figure 5.a and 5.c), a difference of jaw position was obviously present in C1 (/**k**#s/>/**k**#p/). However, there was neither main effect of Speech rate on vertical jaw position (fast=comfortable) (F[1,3]=1.67, $p>0.05$) (Figure 8.b), nor a significant interaction between factors ($p>0.05$).

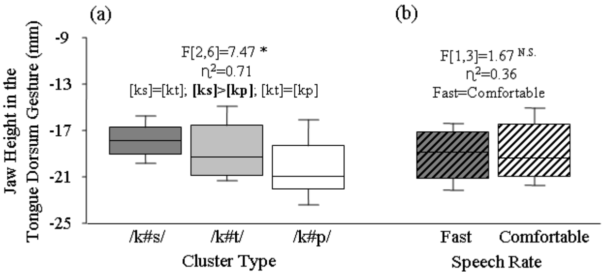


Figure 8. Jaw height in C1, /k/, as a function of (a) Cluster type and (b) Speech rate. ('*' refers to $p<0.05$; '>' denotes significant difference between levels and '=' no statistical difference.)

3.4 Relationship between vertical jaw position in C2 and vertical jaw position in C1

Jaw position in C1 did not correspond exactly to that of C2. The difference in vertical jaw position (/**k**#s/>/**k**#p/) was regularly observed both in C1 and C2 while C2 also exhibited a difference between /k#**t**/ and /k#**p**/ in C2 (/**k**#s/≥/**k**#p/; /**k**#t/>/**k**#p/). Nevertheless, the results of regression analyses with jaw height in C2 against jaw height in C1 confirmed that they are closely related ($R^2=0.94$, F[1,190]=3032.77, $p<0.0001$) (Figure 9), suggesting that a significant amount of variation in the vertical jaw position in C1 is explained by vertical jaw articulation in C2 (ca. 94%). In particular, the vertical jaw position in C1 was more elevated with higher jaw position in C2 (r=0.97, $p<0.0001$).

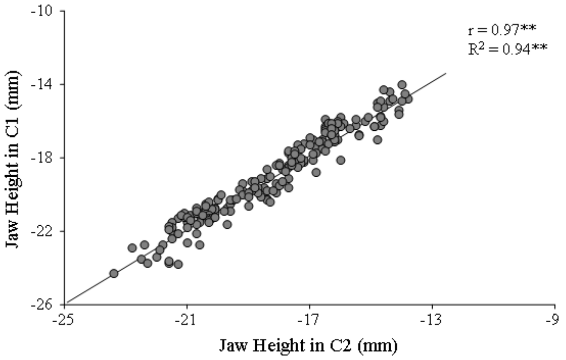


Figure 9. The covariate relationship between actual jaw position in C1 (/k/) with respect to actual jaw position in C2 (/s/, /t/, and /p/). ('**' refers to $p<0.0001$.)

3.5 Relationship between gaps in jaw height between C1 and C2 and gestural overlap

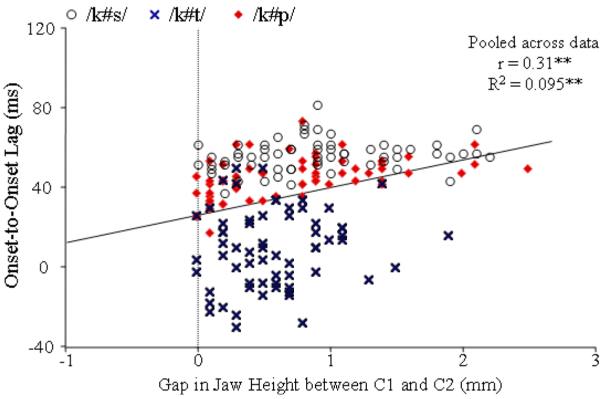


Figure 10. The covariate relationship between gaps in the jaw height between C1 (/k/) and C2 (either /s/, /t/, or /p/) and the onset-to-onset lag in C1C2 sequences. Greater onset-to-onset lag values indicate less inter-gestural overlap between C1 and C2. Positive onset-to-onset lag values indicate that the initiation of C2 follows that of C2, and negative onset-to-onset lag values indicate that the initiation of C2 precedes that of C1. ('**' refers to $p<0.0001$.)

The results of regression analyses with gaps in jaw height against gestural overlap (i.e., onset-to-onset lag) confirmed that the two variables are closely related (ca. 9.5%) (R^2=0.095, F[1,190]=19.97, $p<0.0001$) (Figure 10). In particular, a greater gap in jaw height between C1 and C2 was associated with greater onset-to-onset lag values (i.e., less gestural overlap). However, looking at each cluster type separately, not all sequence types always conform to the results of pooled data. Distance of jaw position of C1C2 sequences and gestural overlap were not related for /k#s/ sequences and for /k#t/ sequences (R^2=0.035, F[1,62]=2.23; R^2=0.019, F[1,62]=1.07, all at $p>0.05$) while the results of /k#p/ sequences yielded significance (R^2=0.24, F[1,62]=19.57, $p<0.0001$). In particular, /k#t/ sequences even demonstrated earlier initiation of the gestural onset of a coronal (/t/) in C2 prior to that of a velar (/k/) in C1 (about 33% of occurrences). This means that only small changes in gestural overlap arose in response to jaw height fluctuation between C1 and C2 in lingual-lingual sequences.

4. Summary and Discussion

Previous articulatory studies on place assimilation have consistently reported that targets of Korean place assimilation demonstrate a wide spectrum of kinematic properties such as deletion and partial reduction to varying degrees (Jun, 1995, 1996, 2004; Kochetov & Pouplier, 2008; Son, 2008b among others). In contrast, nontargets of place assimilation within nonassimilating contexts have not been generally explored in a systematic way beyond nonassimilating controls. In this study we have investigated a velar (/k/) in coda position within three nonassimilating contexts (/k#s/, /k#t/, and /k#p/). Confining the scope of our study to the across-word boundary condition, we analyzed several kinematic characteristics of tongue dorsum, tongue tip, lip aperture, and jaw data. In this section, the main results from section 3 are summarized and discussed.

4.1 Invariant internal cues

Note that greater resistance to perceptual place assimilation was confined to nontargets of place assimilation in Chen's (2003) experiment using gestural stimulation and a recovery algorithm. A labial within nonassimilating /b#d/ sequences ('ba**b** **d**an') was more resistant to perceptual place assimilation than a coronal within assimilating /d#b/ sequences ('ba**d** **b**an'). The present study showed that constriction duration and constriction degree of a velar (/k/) did not vary within various nonassimilating contexts (/k#s/=/k#t/=/k#p/). Moreover, not a single token was categorically reduced across subjects. In addition, speech rate effects on both variables were not observed for either variable. The invariance of spatiotemporal properties during constriction duration in a velar (/k/) within nonassimilating contexts can be interpreted as a manifestation of a good perceptual cue in the sense that those properties are robust articulatory cues for listeners' perceptual recovery.

However, the results of our current study are somewhat incompatible with other articulatory studies on nonassimilating controls (/pt/, /kt/, and /kp/) in the word-internal and across-word conditions. In Kochetov and Pouplier (2008), there were several tokens which were clearly interpreted as partially reduced tokens within /kp/ sequences from one out of three speakers. The difference in reduction may be due in part to different statistical methodologies. Note that Kochetov and Pouplier's (2008) used estimated values of each data point while the current study used the individual means of four subjects for each phonological condition (Cluster type and Speech rate) as the units of analyses. Using the same statistical methodologies, a velar (/k/) in the coda demonstrated a shorter constriction duration as compared to one in the onset (/**k**+t/</t+**k**/) (Son, 2011b). Although a velar is not normally known to be the target of place assimilation, there is some evidence of spatiotemporal reduction of a velar (/k/). However, caution should be taken before we accept the weak and variant status of a velar. Reduction in a velar (/k/) could have been a manifestation of general coda reduction processes (/ak.a/</a.ka/) (Son, 2011c), possibly apart from adjacent segmental effects. A similar pattern was observed in American English where coda reduction generally occurred in all primary articulators (coronal, labial, and velar) in the supralaryngeal level, with more and extreme reduction confined to a coronal /t/.

Taking the phonemic inventory of Korean into consideration, we conjecture that it is less likely that partial reduction in constriction degree in a velar (/k/) may affect listeners' perception of place of articulation, if there is any. Since only oral stop (/k/) and a nasal stop (/ŋ/) are produced in the region of the soft palate, partial reduction in the spatial dimension would not be confusable with anything else (see English listeners' parsing of a voiced uvular stop (/ɢ/) as a velar stop (/g/) in Polka (1992)), which in turn would have been quickly recovered as a velar stop and subsequently resistant to place assimilation. In contrast, diverse manners are articulated in the bilabial region (e.g., an oral stop (/p/), a nasal stop (/m/), and an approximant (/w/)). Hence, it might be possible that partial reduction in the spatial dimension could have been less tolerant of small phonetic changes. Over time, listeners could have been exposed to recurrence of an unfavorable phonetic form of labials (/p/ and /m/) since a partially reduced labial gesture did not clearly belong to either /p/, /m/, or /w/. For this reason, we conjecture that weak perceptibility could have influenced at least in part the targeting of labials in Korean place assimilation, not velars.

4.2 Coronal as a nontrigger

According to Jun's (1995) survey on the typology of place assimilation in his seventeen sample languages, coronals rarely become the trigger of place assimilation crosslingustically (Jun, 1995)－coronals do not become a trigger unless noncoronals do (e.g., /na+mi:**n**+**m**i:n/→[nami:**mm**i:n] 'he cut (with a knife).'; /na+ti:**ŋ**+**t**i:ŋ/→[nati:**nt**i:ŋ] 'he cut (it) through.' in Diola-Fogny from Sapir (1965:16)). Unlike Diola-Fogny, coronals never become triggers in Korean. As a possible reason for coronals as nontriggers in Korean, less gestural overlap was ascribed to nonassimilation. In particular, less gestural overlap was consistently observed in nonassimilating sequences (/p+t/, /p#t/) than in assimilating sequences (/p+k/, /p#k/) as a function of phonological context effects (Son, 2008a). Another piece of evidence to support phonological context effects on gestural overlap was found within word-internal nonassimilating sequences with a coronal (/t/) in C2. In particular, similarity in gestural overlap was observed regardless of the place of articulation in C1 (labial (/p/) vs. velar (/k/)) or order effects within the oral tract (front-to-back (/p+t/) vs. back-to-front (/k+t/)) (Son, 2011; cf. /pt/>/kt/ in Kochetov et al. (2007), where data included both word-internal and across-word boundary conditions). Based on the previous study, we anticipated similar degrees in overlap within nonassimilating contexts such as /k#p/ and /k#t/. However, the results of our current study showed more gestural overlap with the following coronal (/k#**p**/</k#**t**/). What could have brought about this unexpected pattern? Given that place assimilation occurs (in part) as a function of gestural overlap, gestural overlap with a labial (/p/) in C2 would have been more plausible. A possible motive for more gestural overlap with a coronal in C2 than a labial within nonassimilating contexts can be found in Byrd's (1992) experiment on perceptual place assimilation using synthesized speech materials. In particular, extreme gestural overlap from a coronal (/d/) in C2 did not give rise to American-English listeners' assimilated responses in a labial (/b/ in /b#d/ sequences) in C1. That is, decent amounts of gestural overlap from a labial (/b/) in C1 could prompt listeners' assimilated perception. In light of this, the results of our current study may indicate that Korean speakers possess phonological knowledge of gestural overlap even in nonassimilating contexts

such that more overlap with a labial (/p/) in C2 could have hindered the correct recovery of the location of C1 (/k/ in this case) in the oral tract. By contrast, Korean speakers may know that substantial amounts of gestural overlap with the following coronals would not have substantially hindered the perception of the location of C1, and thus speakers allow much gestural overlap from a coronal (/t/).

4.3 The supplementary jaw articulator in coordination with gestural overlap of primary articulators

Taking into account gestural overlap as one of the inducing factors in phonological changes such as place assimilation, articulatory studies have been exploring the possible constraints behind it. In reviewing results from various articulatory studies on Korean place assimilation, we found that empirical evidence reflected that phonological knowledge of gestural overlap controlled in part intergestural overlap in the phonological representation of Korean. However, crosslinguistic studies also demonstrated *low-level speech motor constraints* on jaw height or lingual articulators at work in some languages (see Kühnert et al. (2006) for French ([pn]>[kn]; [pl]>[kl]), Gao et al. (2011) for Taiwanese ([pt]>[pk]), and Kochetov et al. (2007) for Korean ([pt]>[kt]; cf. similarity in gestural overlap ([pt]=[kt]) in Son (2011a)), while other languages displayed puzzling cases (see Kochetov et al. (2007) for Russian ([kt]>[pt]); Gao et al. (2011) for English ([pk]≥[pt])). In particular, the supplementary jaw articulator was known to contribute to different degrees in gestural overlap－high jaw position in C1 occurred in anticipation of high jaw position in C2 with low-cost articulatory effort, which could in turn produce more overlap in primary articulators (e.g., synchronous intergestual timing relations).

The results of the present study showed that the vertical jaw position in C1 was apparently influenced by that of C2 (see Figure 9 in section 3.3.2). In relation to the influence of reduced jaw positional distance between C1 and C2 on gestural overlap, intergestural timing was sensitive to distance of jaw position: more reduced jaw distance between C1 and C2 corresponded to synchronous intergestual timing (r=0.31, R^2=0.095, F[1,190] =19.97, p<0.0001). Despite the established relationship, we nevertheless encounter a dilemma in that how Korean ended up displaying less overlap in [ks] than in [kt] without an established jaw height difference in C2 (/s/ vs. /t/). To solve this dilemma, we conducted independent samples t-tests as supplementary statistical analysis to RM ANOVA, the latter of which was given only one piece of data from each subject per condition. The results showed that vertical jaw position of /s/ was higher than that of /t/ and that a greater gap in /k#s/ was observed as compared to /k#t/ (t(96.1)=3.89; t(110.6)=3.65, all at p<0.0001). Based on these additional statistical analyses, we at least confirmed that the jaw articulator is actively coordinating gestural overlap in C1C2 sequences within Korean nonassimilating sequences (cf., see Byrd & Tan (1996) for American English (/g#s/>/g#d/); Gao et al. (2011) for American English (/p#k/≥/p#t/); See Kochetov et al. (2007) for Russian (/k#t/>/p#t/)).

Acknowledgement

We are especially grateful to four speakers for their participation in the EMMA experiment, as well as to Leonardo Oliveira and Man Gao for their assistance with kinematic data acquisition and to Sean C. O'Rourke for his proofreading of this work.

References

Beckman, M. Edwards, J., & Fletcher, J. (1992). Prosodic structure and tempo in a sonority model of articulatory dynamics. In G. J. Docherty & D. R. Ladd (Eds.), *Papers in Laboratory Phonology II: Segment, Gesture, and Prosody* (pp. 68-86). Cambridge: Cambridge University Press.

Browman, C. & Goldstein, L. (1989). Articulatory gesture as phonological units. *Phonology*, Vol. 6, 201-251.

Browman, C. & Goldstein, L. (1991). Tiers in articulatory phonology, with some implications for casual speech. In J. Kingston & M. E. Beckman (Eds.), *Papers in Laboratory Phonology I: Between the grammar and the physics of speech* (pp. 341-376). Cambridge: Cambridge University Press.

Browman, C & Goldstein, L. (1995). Gestural syllable position effects in American English. In F. Bell-Berti & L. J. Raphael (Eds.), *Producing Speech: Contemporary Issues* (pp. 19-33). Woodbury, N.Y., AIP Press.

Byrd. D. (1992) Perception of assimilation in consonant clusters: A gestural model. *Phonetica,* Vol. 49, 1-24.

Byrd, D. (1996). Influences on articulatory timing in consonant sequences. *Journal of Phonetics*, Vol. 24, 209-244.

Byrd, D. & Tan. C. (1996). Saying consonant clusters quickly. *Journal of Phonetics*, Vol. 24. 263-282.

Chen, L. (2003). Evidence for the role of gestural overlap in consonant place assimilation, *Proceedings of the XV International Congress of Phonetic Sciences*, 2831-2824.

Chitoran, I., Goldstein, L., & Byrd, D. (2002). Gestrural overlap and recoverability: Articulatory evidence from Georgian. In C. Gussenhoven and N. Warner (Eds.), *Laboratory phonology VII* (pp. 419--448). Berlin: Mouton de Gruyter.

Cho, Young-Mee Yu. (1990). *Parameters of consonantal assimilation*. Ph.D. dissertation. Stanford University.

Chomsky, N. & Halle, M. (1968). *The sound pattern of English*. New York: Harper and Row.

Clements, G. (1985). The geometry of phonological features. *Phonology Yearbook*, Vol. 2, 225-252.

Gao, M., Mooshammer, C., Nam, H., Tiede, M., Chang, Y., Hsieh, F., & Goldstein, L. (2011). Intra-and inter-syllabic coordination: An articulatory study of Taiwanese and English. *Proceedings of XVI International Congress of Phonetic Sciences*, 723-736.

Honorof, D. (1999). *Articulatory Gestures and Spanish Nasal Assimilation*. Ph.D. Dissertation, Yale University.

Huynh, H. & Feldt, L. S. (1970). Conditions under which mean square ratios in repeated measurements designs have exact F-distributions. *Journal of the American Statistical Association*, Vol. 65, 1582-1589.

Jacobson, R. Fant, G., & Halle, M. (1963). *Priliminaries to Speech Analysis: The Distinctive Features and Their Correlates*. 3rd printing. Cambridge, MA: MIT Press.

Jun, J. (1995). *Perceptual and Articulatory Factors in Place Assimilation: An Optimality Theoretic Approach*. Ph.D. dissertation. University of California, Los Angeles.

Jun, J. (1996). Place assimilation is not the result of gestural overlap: Evidence from Korean and English. *Phonology*, Vol. 13, 377-407.

Jun, Jongho (2004). Place assimilation. In B. Hayes, R. Kirchner and D. Steriade (Eds.), *Phonetically Based Phonology* (pp 58-86). Cambridge: Cambridge University Press.

Keating, P., Lindblom, B., Lubker, J. & Kreiman, J. (1994). Variability in jaw height for segments in English and Swedish VCVs. *Journal of Phonetics*, Vol. 22, 407-422.

Kim-Renaud, Y-K. (1974). *Korean consonantal phonology*. Ph.D. dissertation. University of Hawaii.

Kochetove, A., Pouplier, M, & Son, M. (2007). Cross-language differences in overlap and assimilation patterns in Korean and Russian. *Proceedings of XVI International Congress of Phonetic Sciences*, 1361-1364.

Kochetov, A. & Pouplier, M. (2008). Phonetic variability and grammatical knowledge: An articulatory study of Korean place assimilation. *Phonology*. Vol. 25, 399-431.

Kühnert, B. & Hoole, P. (2004). Speaker-specific kinematic properties of alveolar reductions in English and German. *Clinical Linguistics and Phonetics*, Vol. 18, 559-575.

Kühnert, B, Hoole, P, & Mooshammer, T. (2006). Gestural overlap and c-center in selected French consonant clusters. *Proceedings of the 7th International Seminar on Speech Production*, 327-334.

Nolan, Francis. (1992). The descriptive role of segments: Evidence from assimilation. In G. Docherty and D. R. Ladd (Eds.), *Paper in Laboratory Phonology II: Segment, Gesture, and Tone*, (pp. 261-280). Cambridge: Cambridge University Press.

Max, L. & Onghena, P. (1999). Some issues in the statistical analysis of completely randomized and repeated measures designs for speech, language, and hearing research. *Journal of Speech, Language, and Hearing Research*, Vol. 42, 261-270.

McCarthy, J. & Taub, A. (1991). The spacial status of coronals; internal and external evidence. *Phonology*, Vol. 9, 363-370.

Mooshmmer, C., Hoole, P., & Geumann, A. (2007). Jaw and order. *Language and Speech,* Vol. 50, 145-176.

Paradis, C & Prunet, J-F. (1991). *Phonetics and phonology: The special status of coronals: Internal and external evidence. Phonetics and Phonology 2*, Academic Press.

Perkell, J., Cohen, M., Svirsky, M., Matthies, M., Garabieta, I., & Jackson, M. (1992). Electromagnetic midsagittal articulometer (EMMA) systems for transducing speech articulatory movements. *Journal of the Acoustical Society of America*, Vol. 92, 3078-3096.

Polka, L. (1992). Characterizing the influence of native langauge experience on adult speech perception. *Perception and Psychophysics*, Vol. 52, 37-52.

Sapir, D. (1965). *A grammar of Diola-Fogny*. Cambridge: Cambridge University Press.

Son, M. (2008). Gestural overlap as a function of assimilation contrast. *Korean Journal of Language*, Vol. 33, 665-691.
(손민정 (2008). 동화 대비 작용에 의한 조음 중첩. 언어 33권, 665-691.)

Son, M. (2008). Gradient reduction of C1 in /pk/ sequences. *Speech Sciences*, Vol. 15, 43-65.
(손민정 (2008). /pk/ 연속음에 나타난 조음 중감, 음성과학 15권, 43-65.)

Son, M. (2011). A language-specific physiological motor constraint in Korean non-assimilating consonant sequences. *Phonetics and Speech Sciences*, Vol. 3, 27-33.

(손민정 (2011). 한국어 비동화 자음 연속음에 나타난 언어 개별적 생리학적 운동 제약. 말소리와 음성과학 3권, 27-33.)

Son, M. (2011). Coordinations of articulators in Korean place assimilation. *Phonetics and Speech Sciences*, Vol. 2, 29-35.

(손민정 (2011). 한국어 위치동화에 나타난 조음자 협력. 말소리와 음성과학 2권, 29-35.)

Son, M. (2011). The projection of syllable structure: A case study of intervocalic /k/ in Korean. *Korean Journal of Language*, Vol. 36, 395-414.

(손민정 (2011). 음절 구조 투사: 한국어 모음 간 /k/ 에 관한 사례 연구. 언어 36권, 395-414.)

Son, M., Kochetov, A., & Pouplier, M. (2007). The role of gestural overlap in perceptual place assimilation: Evidence from Korean, in J. Cole & J. I. Hualde (Eds). *Papers in Laboratory Phonology IX* (pp. 507-534). Berlin, New York: Mouton de Gruyter.

Steriade, D. (1995). Underspecification and markedness, in J. Goldsmith (Ed.). *The Handbook of Phonological Theory* (pp. 114-174). Oxford and Cambridge, MA: Basil Blackwell.

Tiede, M. (2005). MVIEWi: Software for visualization and analysis of concurrently recorded movement data.

Westbury, J. (1994). On coordinate system and the represnation of arituculatory movements. *Journal of the Acoustical Society of America*, Vol. 95, 2271-2273.

Zsiga, E. (1994). Acoustic evidence for gestural overlap in consonant sequences. *Journal of Phonetics* 22, 121-140.

- **Minjung Son**
  Department of Children's English
  Hannam University
  70 Hannam-ro, Daedeok-gu, Daejeon, Korea
  Email: minjungson@hnu.kr